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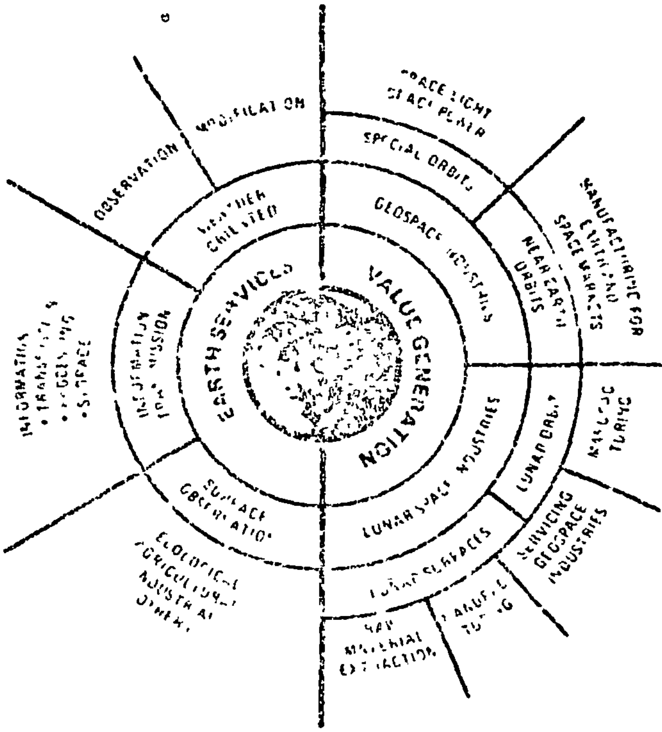
Space Industrialization



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SPACE INDUSTRIALIZATION IMPLEMENTATION CONCEPTS

FINAL REPORT

Rockwell International
Space Division

SD 78-AP-0055-3

Space Industrialization

Final Report

Volume 3. Space Industrialization Implementation Concepts

April 14, 1978

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Space Division

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FOREWORD

This $190,000 Space Industrialization Study was performed under NASA Contract NAS8-32198 for Marshall Space Flight Center from September 1976 through April 1978 The study was in two parts Part 1 identified the potential goals for space industrialization and developed and assessed evolutionary program options for realization of those goals, Part 2 defined program support demands, evaluated and defined the leading program options, and developed recommendations for program implementation The study results are documented in four volumes

1 Executive Summary

2 Space Industrialization Background, Needs, and Opportunities

3 Space Industrialization Implementation Concepts

4 Appendixes

The Rockwell study manager was Mr C L Gould Other key Rockwell participants were A D. Kazanowski and T S Logsdon Additional support was provided by D B Anderson, C R Gerber, and J A Sackinger Many others helped in various ways They included the following key consultants

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The study was performed under the technical direction of C C Priest, Marshall Space Flight Center Mr J von Puttkamer was the overall program manager at NASA Headquarters, Office of Space Transportation Systems Major contributions were also made at special working group meetings by the following

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Ranking of Program Options
Time Phasing for Six Program Options

INITIAL PROGRAM OPTIONS AND EVALUATION

INTRODUCTION

This volume of the *Space Industrialization* study deals mostly with the methods for selecting the most viable program options and the techniques whereby the hardware is developed and integrated into a series of functioning systems in a reasonable time frame and in accordance with realistic cost estimates.

In the initial sections of this volume, we will define six separate program options and then we will set up a common sense selection process to narrow down the list to the best candidates, as seen from the viewpoint of the Rockwell analysis team. Next, we will mesh these selections with similar results that were developed by Science Applications, Inc. (SAI) — which flowed from a parallel study using roughly parallel methods. The final result is a set of three plans for future exploitation of the space frontier. Each separate plan hinges largely on the decision and timing for go-ahead on the SPS project.

Hardware elements in various sectors of space are then discussed in sufficient depth to provide a definition of the major functional elements and the major operations. These elements include:

a. Shuttle-Tended and Space-Base Facilities
b. Space Processing Facilities
c. Geosynchronous Orbit Facilities
d. High Inclination Orbit Facilities
e. SPS Development Activities
f. Data Relay Satellites
g. Lunar Facilities and Operations
h. Transportation Hardware

Once these elements have been defined to a reasonable level of detail, we will present cost estimates for the various hardware elements and programmatic plans for the installation and operation of the principal units in the three separate plans. Finally, all necessary supporting research and technology plans will be advanced with emphasis on the near-term developments that will lead in the direction of the envisioned plans.

INITIAL PROGRAM OPTIONS AND EVALUATION

Our approach to developing an encompassing range of program options was to formulate a set of varying philosophies stemming from general future trends. Three futures were evaluated:

2. Near-term orientation decision-making
3. Long-term orientation decision-making
4. Basic environmental change (35-year cold period, e.g., a *little ice age*)

Each of these futures results in one or more possible decision options for future generations. In keeping with the goals of the study, we developed a total of six program options (as sketched in Figure). As can be seen, the Foresight future results in two program options; one oriented around international cooperation and the other oriented around leadership at the geosynchronous orbit. In addition, the *future commonality* option results from an extraction of those elements that are common to all three of the other futures.

The six program options shown in Figure 1 are discussed in the next six paragraphs.

1. *IMMEDIATE CRISIS-ORIENTED PROGRAM* — In accordance with this option, the public views our country as having so many pressing problems that they do not feel they can justify sacrificing today for a better tomorrow. In general, the space program and other long-lead time opportunities will be postponed continually unless they have a crisis aura. Business will do what shows near-term payoff, and government will support what seems to be a near-term solution to a recognized immediate crisis. As the future evolves, new crises will precipitate various space program solutions, but in each case only those opportunities that can be accomplished quickly will be included.

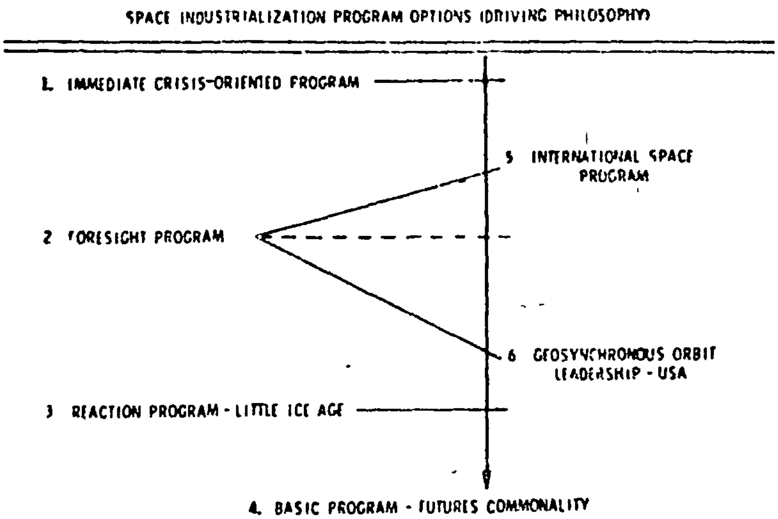


Figure 1. Space Industrialization Program Options

2. *FORESIGHT PROGRAM* — If this philosophy is followed, the United States Government is willing to look ahead for two or more decades and support those investments that are clearly shown to be directly beneficial to national and international interests. The national feel is one of basic confidence in the future, but the necessity to cope with energy, productivity, and balance-of-payment needs are understood. In this future we seek also to develop a strong synergistic interrelationship between developed and developing countries for both humanitarian and business reasons. We are dedicated to help worldwide industrialization on a progress curve that outpaces population growth, and to develop customers with buying power for our higher technology products and services.

3. *REACTION PROGRAM (LITTLE ICE AGE)* — This future assumes that data are available which clearly convince our population that a 30-year cooling-off period has begun such that a World War II-like national motivation becomes real. As a result, approximately 10 percent of our GNP would be dedicated to terrestrial and space investments that are clearly beneficial in mitigating the bad effects upon the United States.

4. *BASIC PROGRAM (FUTURES COMMONALITY)* — This philosophy calls for a play-it-safe approach that warrants a reasonable investment in space activities common to the basic futures identified. It is not strictly nationalistic, but international assistance is secondary in priority since the crisis influences of Futures 1 and 3 are strong.

5. *INTERNATIONAL SPACE PROGRAM* — The driving philosophy in this program option is that full world participation in space activities will tend to ease friction and foster world peace. A press to have all countries participate and share the benefits tends to override purely technical and business considerations.

6. *GEOSYNCHRONOUS MARKET LEADERSHIP* — The fundamental driver in this program is to recognize the value of world market leadership in the information business. A key to this market is the utilization of space, particularly geosynchronous orbit, for an ever-changing variety of services. We would aim to keep ahead of the competition in the space segment, the multiplicity of corresponding ground equipment, and the number and quality of benefits provided.

RANKING OF THE PROGRAM OPTIONS

During the course of the *Space Industrialization* study, parallel efforts were conducted to extrapolate both mankind's needs and technical opportunities into the future. The needs were than used to trigger new ideas for space opportunities that might have been previously overlooked and as a background for evaluation of these opportunities, both relative to each other and relative to competitive terrestrial options. This process yielded some 300 specific needs (there could be many more depending on how they are broken down) and some 200 space opportunities. By evaluation and combination, the 200 opportunities were pared to about 100, each of which was then written up to a specific 12-point format for more detailed evaluation. It was intended to reduce the list to some 25 outstanding opportunities upon which an evolutionary space program could be firmly anchored. As the evaluation proceeded, however, we found it surprisingly difficult to throw out very many of the opportunities. The list still numbers about 50, each of which seems worthwhile and cost-effective to do sometime before the year 2025.

As we looked at the options and the opportunities, we talked to many space experts and other interested people, both within the company and outside, and in and out of the aerospace industry. About 100 evaluators, young and old and of various ethnic and technical backgrounds, helped us come to the following conclusions:

1. Option 1 should surely be done. It is the least we should do and its implementation should be simply a matter of getting the facts understood to the Congress, OMB, and the American people.

2. We in the aerospace community have a definite obligation to pursue the foresight options at least in our own plans. Moreover, we have an obligation to get as much support as we can. Unfortunately, we know that Congress and the public, as a whole, are not future-oriented, so this program option has little chance of full implementation. The best that we can hope is that it can be partially brought about.

3. The two oblique foresight options — one seeking the primary emphasis to be on international funding and participation (No. 5) and the other seeking to deliberately nourish a potential information systems market for the United States (No. 6) — are now as viable as the middle route. True international cooperation is extremely difficult to turn into reality, but on the other hand, too self-serving an approach implemented by any country is apt to meet strong resistance by most of the other countries. We do feel that a reasonable market leadership in this area is a *natural* for the United States and should be supported by Government action.

4. Program Option 3 (Reaction Program - Little Ice Age) is actually a specific kind of foresight (No. 2) that predicts an immediate crisis (No. 1) at a future time. This particular crisis, if it should appear to be coming (as the climate patterns are studied and experienced), has such an overriding influence that it is prudent foresight at least to develop long-lead precursors to the accelerated space activities indicated.

5. The Futures Commonality Program Option (No. 4) does not make as much sense as a commonality of opportunities as it does as a commonality of hardware and technology for use in the systems that implement these opportunities. These hardware commonalities will be determined at a later date when the characteristics of the system hardware items are better defined.

TIME PHASING FOR THE SIX PROGRAM OPTIONS

As has been mentioned, the process of studying and integrating world future needs and space program opportunities into options for a *Space Industrialization* program resulted in the selection of three futures, against which the some 200 opportunities were measured. After much study, these were narrowed down to some 50 *anchor opportunities*. Each of these anchor opportunities applies solidly to at least one of the futures cited and to several of the many important world needs that have been identified in the previous analysis.

In essence, the first future (Immediate Crisis Orientation) assumes continued preoccupation with short-term, more or less immediate results and implies less than desirable preparedness to counteract longer-term trends building up toward crises (i.e., a dificiency in investing in future options).

The second future (Foresight) places greater emphasis on long-term orientation. The approach is one of more active future-shaping by counteracting negative trends earlier and by building up options to deal with future problems.

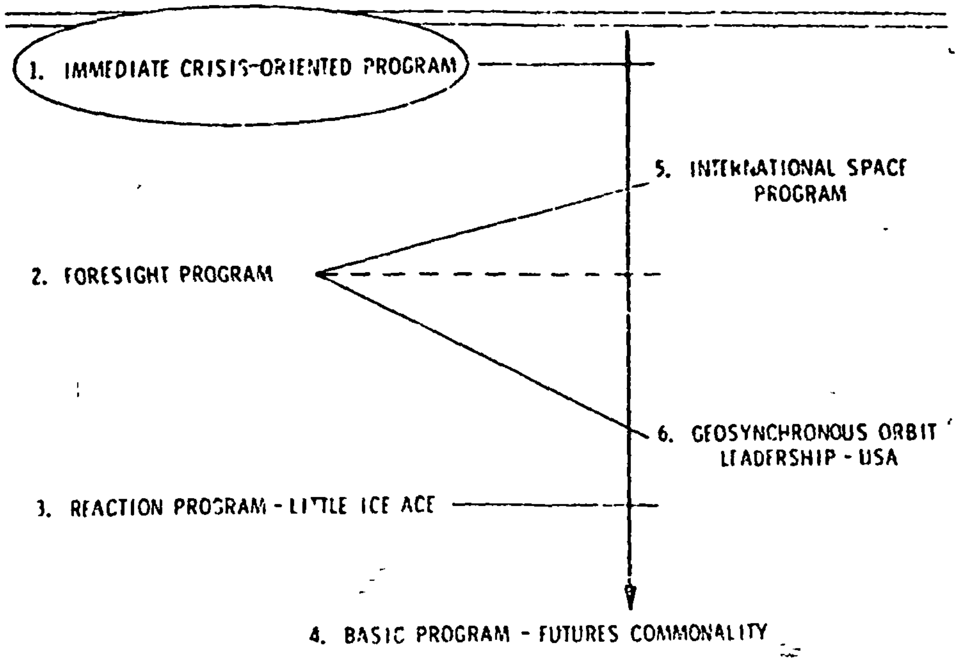
The third future (Little Ice Age) assumes a major change not under human control. The change postulated a 35-year cold period, causes the future situation to be dominated by the need to respond to a series of protracted and, for some time worsening, emergencies.

In Figures 2 through 7, individual definitions of the six program options are presented (one-by-one), each option is developed in a standard format, and the report is printed so that the program options can be studied individually in a convenient way without back-and-forth turning of pages. The top part of each figure names all six options and shows how they stem from the futures, but still interrelate. The driving philosophy of each one is shown below the interrelationship chart. The resultant effect of applying that philosophy to the anchor opportunities is shown on each right-hand page. The most important information on each set of pages is crowded into the center region of each right-hand page; note that in these sections are six options, 54 anchor opportunities, five time-frames, three importance gradients, five level-of-effort gradients — a total of almost 5,000 pieces of information for each option. The results are summarized in narrative form in the boxes on the right. It is in realization of the complexity of understanding these options (without benefit of spoken words or color) that the sheets were developed to put each option on just one page.

The dynamics of changes in each program option take the non-linearity of the futures into account; that is to say, each accomplishment, or even commitment, changes the subsequent frame of reference. Postponement of problem solutions leads to a convergence of problems or crises later on, multiplying the number of new starts. Conversely, earlier option-generating vigor reduces the proliferation of new starts in the latter part of the reference period (1980-2010) and makes it possible to build deliberately on earlier accomplishments. Also, advances change the perspective. What requires much foresight or a big step in 1980 is less demanding on both counts in 1995. Finally, the combinations shown are the first layout. Adjustments may be made in the course of further analysis.

There are two of the opportunities (Oil Spill Detection and Offshore Limit Monitoring) that have been marked out and one was deleted before the sheet was made up. These are ones that initially seemed to be winners, but on detailed investigation of possible terrestrial alternatives did not show an economic advantage. Therefore, these opportunities were dropped out of all programs, but could be reinstated if the space systems that are designed primarily for other missions can accomplish these additional tasks at very little additional cost.

SPACE INDUSTRIALIZATION PROGRAM OPTIONS (DRIVING PHILOSOPHY)



IN ACCORDANCE WITH THIS OPTION THE PUBLIC VIEWS OUR COUNTRY AS HAVING SO MANY PRESSING PROBLEMS THAT THEY DO NOT FEEL THEY CAN JUSTIFY SACRIFICING TODAY FOR A BETTER TOMORROW. IN GENERAL, THE SPACE PROGRAM AND OTHER LONG-LEAD TIME OPPORTUNITIES WILL GET CONTINUALLY POSTPONED UNLESS THEY HAVE A CRISIS AURA. BUSINESS WILL DO WHAT SHOWS NEAR-TERM PAYOFF, AND GOVERNMENT WILL SUPPORT WHAT SEEMS TO BE A NEAR-TERM SOLUTION TO A RECOGNIZED IMMEDIATE CRISIS. AS THE FUTURE EVOLVES, NEW CRISES WILL DEVELOP THAT PRECIPITATE VARIOUS SPACE PROGRAM SOLUTIONS, BUT IN EACH CASE ONLY THOSE OPPORTUNITIES THAT CAN BE DONE REASONABLY QUICKLY WILL BE INCLUDED.

LEGEND

1 Research and development supported at low levels to gain basic understanding

2. Moderately expanding funds for existing projects. Most problems addressed sequentially

3 Funding levels ample, but below accelerated level. Expansions according to needs. Most problems addressed concurrently

4 Availability of funds is not a limiting factor. New programs started according to needs and carried concurrently

5 High national priority assigned to all programs. Technology limitations are the only pacesetters

P = Private. The private sector has taken over the effort

The circles indicate importance level, i.e., it should definitely be done. If the number is not circled, it is still in the program, but is questionable or more subject to cost and schedule compromise. Blank spaces across the whole time span indicate that it would be done only if it comes very cheaply as an add-on to a more important item. Beyond the last number in the sequence the activity is continuing at a routine level (like weather pictures from space). The [illegible] are indicated with stars — either a combination of importance and rate or of major importance in that particular program option.

Figure 2. Immediate Crisis-Oriented Program

1. IMMEDIATE CRISIS – ORIENTED PROGRAM

			Anchor Opportunities / Time Frame	C0-85	85-90	90-95	95-10	10-25	
SERVICES	Transmission	1	Direct Broadcast Education – U.S.	2	3				1
		2	Direct Broadcast Education -- Devel. Countries	2	2	3			2
		3	Business System Data Transfer	1	2	P			3
		☆4	Electronic Telecommuting	1	3	3			4
		5	World Medical Advice Center	1	2	2	3		5
		6	Time and Navigation Services		1	2	2		6
		7	Implanted Sensor Data Collector	1	1	2			7
		8	National Information Services		1	2	2		8
		9	Personal Communications		1	2	3		8
		10	Electronic Mail (Excl. Packages)		1	3	3		10
		☆11	Medical Aid and Information – U.S.	2	3	3			11
		12	Teleoperation From Space				2		12
	Observation	1	Oil/Mineral Location	2	2	2			1
		☆2	Crop Measurement	2	3	3			2
		3	~~Oil Spill Detection~~						3
		4	Ocean Resources and Dynamic System	1	2	2	3		4
		5	Water Resource Map and Runoff Forecast	2	3	2			5
		6	~~Offshore Control Limit Monitoring~~						6
		☆7	Global Effects Monitoring (STO)	2	3	3			7
		8	High Resolution Earth Mapping			2	2		8
		9	High Resolution Thermal Mapping		1	2	2		9
PRODUCTS	Organic	1	Isoenzymes (Medical Diagnostic Tool)	1	2	3			1
		☆2	Urokinase (Anticoagulant)	2	3	P			2
		3	Insulin (From Human Sources)	1	2	2	P		3
	Inorganic	1	Large Crystals (Size and Perfection)	1	2	P			1
		2	Super Large Scale Integrated Circuits	2	P				2
		3	New Glasses (Including Fiber Optics)	2	2	2	P		3
		4	High Temperature Turbine Blades	1	2	2	P		4
		5	High Strength Permanent Magnets	2	P				5
		6	Thin Film Electronic Devices	1	2	P			6
		7	Continuous Ribbon Crystal Growth	1	2	3	P		7
ENERGY	[illegible]	1	Night Illumination for Urban Areas	1	2	2	3 P		1
		2	Night Illumination for Agric. and Indust. Ops		1	2	3 P		2
	Solar	1	Night Frost Damage Protection				2	2	1
		2	Local Climate Manipulation				2	2	2
		3	Stimulation of Photosynthesis Process				1	2	3
		☆4	Reflected Light for Ground-Elect. Conv.				2	4	4
	SPS	☆1	Satellite Power System (Solar)			1	3	4	1
		2	Fusion Power Source for MW						2
	In Space	☆1	Fusion In Space (Research & Operational)	1	1	1	4	5	1
HUMAN ACTIVITIES		1	Medical Research Facility (Biosatellite)	1	2	3	3	P	1
		2	Space Vacation Cruises (Shuttle Mod)	1	2	2	3	3	2
		3	Medical Lab and Facility for Space Personnel		1	3			3
		4	Orbital Tourist Facility						4
		5	Orbital Hospital (Special Low-g Transport)						5
		6	Lunar Tourism						6
LUNAR INDUSTRY		1	Lunar Unmanned Exploration	1	2				1
		2	Lunar Space Station (Manned)		1	2	2		2
		3	Lunar Ground Base (Test, Trans Devel, etc.)			1	3		3
		4	Lunar Oxygen Industry Establishment			1	2		4
		5	Lunar Metal Industry Facilities				2	3	5
		6	Lunar Orbiting Factory				2	3	6
		7	Lunar Ecosphere (Lunar Agriculture)			1	2	3	7
		8	Large Lunar Industrial Zone				2	3	8

Direct Broadcast Education from space opens up a synergism between each individual's immediate education status and the job or skill within his reach, regardless of his location. This, together with electronic telecommuting and improved medical care via space communications links drive the program. The current NASA needs of job expansion coupled with energy costs and shortages are substantially aided via space. The soaring costs of medical care are reduced by getting people out of the hospital and back to home or paramedic [illegible] care much more quickly. The stress, time loss, gasoline, and pollution of travel to and from work is reduced using both space and ground telecommuting techniques.

Immediate needs for improved food production and world-wide distribution (with balance of payments improvement for USA) are helped with crop measurement and water management using Super Landsat systems. In addition, major steps are taken toward fully understanding our weather and climate -- causes/effects, trends, and eventually long range and detailed prediction of specific local weather and climate conditions. Later on, the international trauma related to new 200 mile off shore rights of the world community is eased by making the activities in such areas relatively transparent. Benefiting countries would pay the U.S. for such service via monetary or other means.

Products, particularly growing out of Shuttle/Spacelab research, particularly in the medical field, cause a full awareness of the direct and very personal relationship of space activities to current needs. Other products, particularly those that relate to energy, emerge and grow steadily in significance, but do not drive the program in the 80's and early 90's. Commercial products will emerge that demand large, specialized facilities in the late 90's and beyond. (A single separate facility such as a large crystal-growing factory may be very early, but it would be a small, inexpensive Shuttle tended facility rather than a major space industrialization step.)

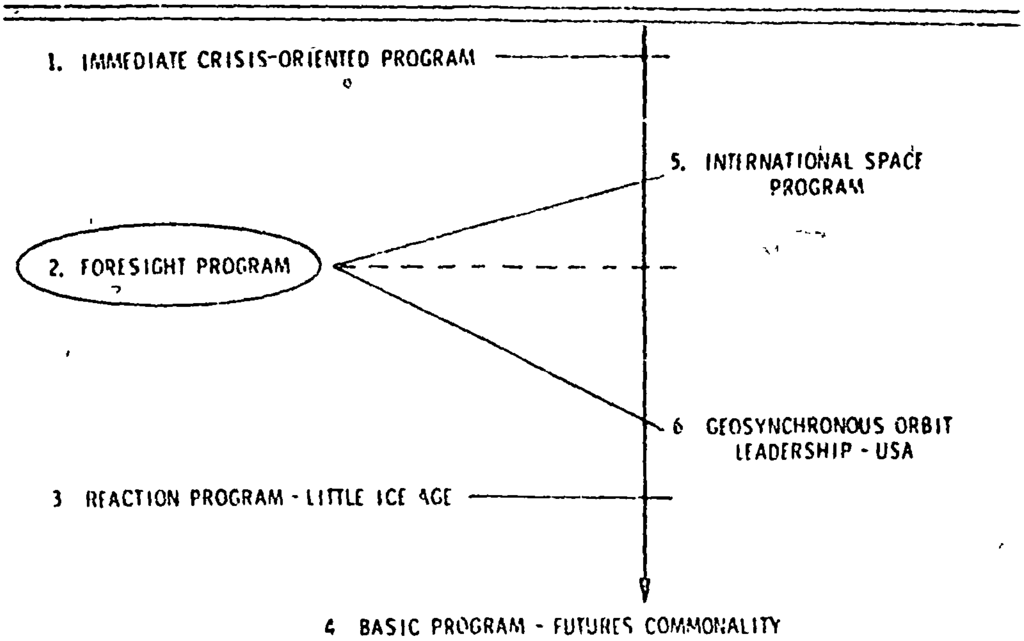
Energy is one of the current crisis concerns and would be the major program driver, if any space solutions can bring major results within a 5 year period after Shuttle IOC. That panacea doesn't seem to exist, but the energy problem will continue to influence [illegible] long term space programs in three major areas: fusion breakthroughs in the space environment, reflected solar energy, and microwave beamed electrical energy (SPS). The feedback effect of short sighted national policy coupled with the normal progress of space capability will eventually bring the space/energy programs into focus and they will begin to be vigorously pursued about the turn of the century.

Human activities basically ride the coat tails of the space program as timed and configured by other things. A possible exception is medical research, particularly the benefit of absolute separation from the world's very integrated biosphere for research that might possibly have major, perhaps catastrophic, consequences of an accident or blessing. In addition, as the number of people living and working in space increases, an increasingly sophisticated on-orbit medical capability will be required.

The lunar industry basically comes along in support of very large things in GSE, first in oxygen supplies for orbit-to-orbit transfer and later with other materials needed for the construction and operation of such things as Solettas and SPS's.

Figure 2. Immediate Crisis Oriented Program (Cont.)

SPACE INDUSTRIALIZATION PROGRAM OPTIONS (DRIVING PHILOSOPHY)



IF THIS PHILOSOPHY IS FOLLOWED, THE UNITED STATES-GOVERNMENT IS WILLING TO LOOK AHEAD FOR TWO OR MORE DECADES AND SUPPORT THOSE INVESTMENTS THAT ARE CLEARLY SHOWN TO BE DIRECTLY BENEFICIAL TO NATIONAL AND INTERNATIONAL INTERESTS THE NATIONAL FEEL IS ONE OF BASIC CONFIDENCE IN THE FUTURE, BUT THE NECESSITY TO COPE WITH ENERGY, PRODUCTIVITY, BALANCE-OF-PAYMENTS, AND NEEDS ARE UNDERSTOOD IN THIS FUTURE WE SEEK ALSO TO DEVELOP A STRONG SYNERGISTIC INTERRELATIONSHIP BETWEEN DEVELOPED AND DEVELOPING COUNTRIES FOR BOTH HUMANITARIAN AND BUSINESS REASONS. WE ARE DEDICATED TO HELPING WORLD-WIDE INDUSTRIALIZATION ON A PROGRESS CURVE THAT OUTPACES POPULATION GROWTH, AND TO DEVELOP CUSTOMERS WITH BUYING POWER FOR OUR HIGHER TECHNOLOGY PRODUCTS AND SERVICES

LEGEND

1 Research and development supported at low levels to gain basic understanding

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Figure 3. Foresight Program

2. FORESIGHT PROGRAM

Area	Group	No.	Anchor Opportunities / Time Frame	80-85	85 90	90 95	85 10	10 25	
SERVICES	Transmission	☆1	Direct Broadcast Education – U S.	2	3	3			1
		☆2	Direct Broadcast Education – Devel Countries	2	3	3			2
		3	Business System Data Transfer	2	P				3
		☆4	Electronic Telecommuting	4	4	4			4
		5	World Medical Advice Center	1	2	2			5
		6	Time and Navigation Services	1	2	2			6
		7	Implanted Sensor Data Collector	2	2	2			7
		8	National Information Services	2	2				8
		9	Personal Communications	2	3P				9
		☆10	Electronic Mail (Excl Packages)	3	4	4			10
		☆11	Medical Aid and Information – U S	3	4	4			11
		12	Teleoperation From Space						12
	Observation	☆1	Oil/Mineral Location	2	3				1
		☆2	Crop Measurement	2	3				2
		3	~~Oil Spill Detection~~						3
		4	Ocean Resources and Dynamic System	2	3	3			4
		☆5	Water Resource Map and Runoff Forecast	2	3				5
		6	~~Offshore Control Limit Monitoring~~						6
		☆7	Global Effects Monitoring (STO)	2	3	4			7
		8	High Resolution Earth Mapping	2	2	2			8
		9	High Resolution Thermal Mapping	2	2	2			9
PRODUCTS	Organic	☆1	Isoenzyme (Medical Diagnostic Tool)	1	2	3	P		1
		☆2	Urokinase (Anticoagulant)	2	3	P			2
		3	Insulin (From Human Sources)	1	2	P			3
	Inorganic	☆1	Large Crystals (Size and Perfection)	2	2	P			1
		☆2	Super-Large Scale Integrated Circuits	3	P				2
		☆3	New Glasses (Including Fiber Optics)	2	3	P			3
		4	High-Temperature Turbine Blades	2	2	P			4
		5	High Strength Permanent Magnets	2	P				5
		☆6	Thin Film Electronic Devices	2	3	P			6
		☆7	Continuous Ribbon Crystal Growth	2	3	P			7
ENERGY	Lunetta	☆1	Night Illumination for Urban Areas	3	4	4	4P		1
		2	Night Illumination for Agric and Indust Ops	3	3	3	3		2
	Soletta	☆1	Night Frost Damage Protection			2	4		1
		2	Local Climate Manipulation			2	3		2
		3	Stimulation of Photosynthesis Process			1	2		3
		4	Reflected Light for Ground Elect Conv.			1	3		4
	SPS	☆1	Satellite Power System (Solar)	2	3	3	4	4	1
		☆2	Fusion Power Source for MW	2	3	4	4	4	2
	In Space	☆1	Fusion In-Space (Research & Operational)	2	3	4	4	4	1
HUMAN ACTIVITIES		1	Medical Research Facility (Biosatellite)	2	3	3			1
		2	Space Vacation Cruises (Shuttle Mod)	1	2	3			2
		3	Medical Lab and Facility for Space Personnel	2	3	3			3
		4	Orbital Tourist Facility				2		4
		5	Orbital Hospital (Special Low-g Transport)				2		5
		6	Lunar Tourism				2	3	6
LUNAR INDUSTRY		1	Lunar Unmanned Exploration	1	3				1
		2	Lunar Space Station (Manned)		2	3			2
		3	Lunar Ground Base (Test, Trans Devel, etc)		2	3	4		3
		4	Lunar Oxygen Industry Establishment			2	4		4
		5	Lunar Metal Industry Facilities				3		5
		6	Lunar Orbiting Factory				3		6
		7	Lunar Ecosphere (Lunar Agriculture)			2	4		7
		8	Large Lunar Industrial Zone				2	4	8

Electronic telecommunicating is Government sponsored/encouraged and begins to change the nation's life-style and characteristics to a much more energy-efficient situation People tend to travel only short distances to work and smaller urban units have the education and job flexibility now only enjoyed by the few megalopolis areas (New York, Los Angeles, Chicago, etc) in the U S The trend toward long hospitalization and attendant soaring costs is reversed by the medical aid available via telecommunication direct to patients in their home, aided by minor training of the family and medical aid personnel The direct-from-space education/job situation mentioned in Program Option I develops as previously discussed

Observation services get carried out, essentially as in Program Option I except that the long-term benefits to the U S that would occur from a synergistically beneficial relationship with developing countries is emphasized Overall, vantage point of space is used broadly for long-term reasons rather than heavy concentration on the immediate and obvious problems of food, water, energy, and climate

Our foresight tells us that there will be made-in-space products of great value both to the space market and earth markets The major and immediate steps taken in other space areas in Program Option I generates a larger space market for products than Program Option I However the specific delineation of which products emerge as winners is highly speculative until the Shuttle/Spacelab materials processing experiments are carried out

Although all major contributions to energy problems from either reflected light, microwave or fusion are long lead-time, expensive projects, the overriding importance of energy to the U S and the world leads to step-by-step development of the necessary technology and systems

The pervasive quest and ambition of the human spirit will insist on an expanding personal presence in both earth orbit and on the lunar surface Therefore the space systems developed [illegible] for other reasons should include capability for a wide variety of human activities In this program the beckoning possibility that you may someday be there yourself becomes a subtle configuration determinant in system design and a force toward space program [illegible] (Note that the [illegible] will soon be voters)

The foresight program recognizes the advantage of lunar materials for earth orbit industrial reasons and moves lunar industry forward in time.

Figure 3. Foresight Program (Cont.)

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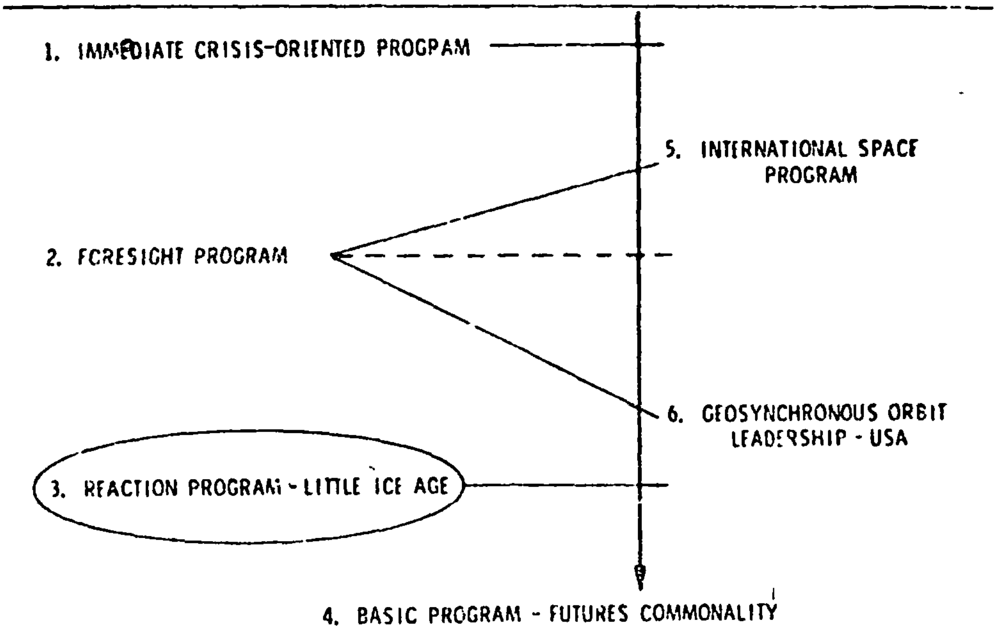
SPACE INDUSTRIALIZATION PROGRAM OPTIONS (DRIVING PHILOSOPHY)



THIS FUTURE ASSUMES THAT DATA ARE AVAILABLE WHICH CLEARLY CONVINCE OUR POPULATION THAT A 30-YEAR COOLING-OFF PERIOD HAS BEGUN SUCH THAT A WORLD WAR II-LIKE NATIONAL MOTIVATION BECOMES REAL, AND SOMETHING LIKE 10 PERCENT OF OUR GNP WOULD BE DEDICATED TO TERRESTRIAL AND SPACE INVESTMENTS THAT ARE CLEARLY BENEFICIAL IN MITIGATING THE BAD EFFECTS UPON THE USA.

LEGEND

1 Research and development supported at low levels to gain basic understanding

2 Moderately expanding funds for existing projects. Most problems addressed sequentially

3 Funding levels ample, but below accelerated level. Expansions according to needs. Most problems addressed concurrently

4 Availability of funds is not a limiting factor. New programs started according to needs and carried concurrently

5 High national priority assigned to all programs. Technology limitations are the only pacesetters

P = Private. The private sector has taken over the effort

The circles indicate importance level, i.e., it should definitely be done. If the number is not circled, it is still in the program, but is questionable or more subject to cost and schedule compromise. Blank spaces across the whole time span indicate that it would be done only if it comes very cheaply as an add-on to a more important item. Beyond the last number in the sequence the activity is continuing at a routine level (like weather pictures from space). The program drivers are indicated with stars -- either a combination of importance and rate or of major importance in that particular program option

Figure 4. Reaction Program—Little Ice Age

3. REACTION PROGRAM – LITTLE ICE AGE

		Anchor Opportunities	Time Frame	80 85	85 90	90 95	95 10	10 25	
SERVICES	Transmission	☆1	Direct Broadcast Education – U S	5	6				1
		2	Direct Broadcast Education – Devel Countries	3	3				2
		☆3	Business System Data Transfer	5	5				3
		☆4	Electronic Telecommuting	5	5				4
		☆5	World Medical Advice Center	6	5				5
		☆6	Time and Navigation Services	3	5				6
		☆7	Implanted Sensor Data Collector	5	6				7
		☆8	National Information Services	5	5				8
		☆9	Personal Communications	3	6				9
		☆10	Electronic Mail (Excl Packages)	3	5				10
		☆11	Medical Aid and Information – U S	6	5				11
		12	Teleoperation From Space			3			12
	Observation	☆1	Oil/Mineral Location	5	5				1
		☆2	Crop Measurement	5	5				2
		3	Oil Spill Detection						3
		☆4	Ocean Resources and Dynamic System	5	5				4
		☆5	Water Resource Map and Runoff Forecast	5	5				5
		6	Offshore Control Limit Monitoring						6
		☆7	Global Effects Monitoring (STO)	5	5				7
		☆8	High Resolution Earth Mapping	5	5				8
		9	High Resolution Thermal Mapping		3				9
PRODUCTS	Organic	1	Isoenzymes (Medical Diagnostic Tool)	3	3				1
		2	Urokinase (Anticoagulant)	3	3				2
		3	Insulin (From Human Sources)						3
	Inorganic	1	Large Crystals (Size and Perfection)						1
		☆2	Super Large Scale Integrated Circuits	5					2
		3	New Glasses (Including Fiber Optics)						3
		☆4	High Temperature Turbine Blades		5				4
		5	High Strength Permanent Magnets						5
		☆6	Thin Film Electronic Devices	5					6
		7	Continuous Ribbon Crystal Growth	3					7
ENERGY	Lunetta	☆1	Night Illumination for Urban Areas	3	5	5	5		1
		☆2	Night Illumination for Agric and Indust Ops	3	5	5	5		2
	Soletta	☆1	Night Frost Damage Protection		2	4	5		1
		☆2	Local Climate Manipulation		2	4	5		2
		☆3	Stimulation of Photosynthesis Process		2	4	5		3
		4	Reflected Light for Ground Elect Conv						4
	SPS	1	Satellite Power System (Solar)						1
		2	Fusion Power Source for MW	2	4	5	5		2
	In Space	☆1	Fusion In Space (Research & Operational)	2	4	4	4	5	1
HUMAN ACTIVITIES		1	Medical Research Facility (Biosatellite)	3					1
		2	Space Vacation Cruises (Shuttle Mod)						2
		3	Medical Lab and Facility for Space Personnel		4	4	5		3
		4	Orbital Tourist Facility						4
		5	Orbital Hospital (Special Low-g Transport)						5
		6	Lunar Tourism						6
LUNAR INDUSTRY		1	Lunar Unmanned Exploration	2	3	4			1
		2	Lunar Space Station (Manned)	2	3	5			2
		3	Lunar Ground Base (Test, Trans Devel, etc)			5			3
		4	Lunar Oxygen Industry Establishment			5	5		4
		5	Lunar Metal Industry Facilities				5		5
		6	Lunar Orbiting Factory				5		6
		7	Lunar Ecosphere (Lunar Agriculture)				3		7
		8	Large Lunar Industrial Zone				3		8

If there is a reasonable possibility that a 30 year *Little* Ice Age has begun, the urgency of beginning immediately on those space (and ground) activities that would mitigate the bad effects shows up in the rapid implementation of those information transmission activities that we know we can do and that we know can be combined into a relatively few actual space systems. Anything that reduces travel, saves energy, increases productivity, or saves lives (when you can't get to the hospital) would be done as soon as prudent engineering and programmatics allow.

Earth observation and climate understanding becomes the major program drivers in this program option. They quickly become of such size, complexity, and importance that they become manned systems in several space locations. The world *north/south* relationship now changes in character and food production and distribution becomes increasingly critical. The capability of U S and Canada to remain major food sources for the world is diminished, but such technology becomes critical for massive disaster avoidance.

The products produced in this option will directly support the production and conservation of energy or in such energy-saving services as electronic telecommuting or education broadcast.

Energy is the other (see services) program driver in this option. Since reflected light (Lunetta) can be done most quickly, it will be done. [illegible] grow and be Lunetta lighted. Agriculture will benefit from Lunetta particularly in opening up new areas where night and day operations are critical in the crop [illegible] due primarily to weather conditions. In addition, even though the Arctic frontier becomes more difficult to exploit, the Lunetta will aid during the winter night. Fusion in space will be pushed on an urgent basis. SPS urgency will give way to Soletta because of the mammoth needs for food and the push toward local weather (frost damage type) control. SPS ground stations are more expensive than in a mild climate and the major benefits of hundreds of SPS's come too little and too late.

Human activities simply ride the coat-tails of a space program orders of magnitude beyond today's funding.

The lunar industry is developed to support the rest of the space program, particularly Soletta.

Figure 4. Reaction Program—Little Ice Age (Cont.)

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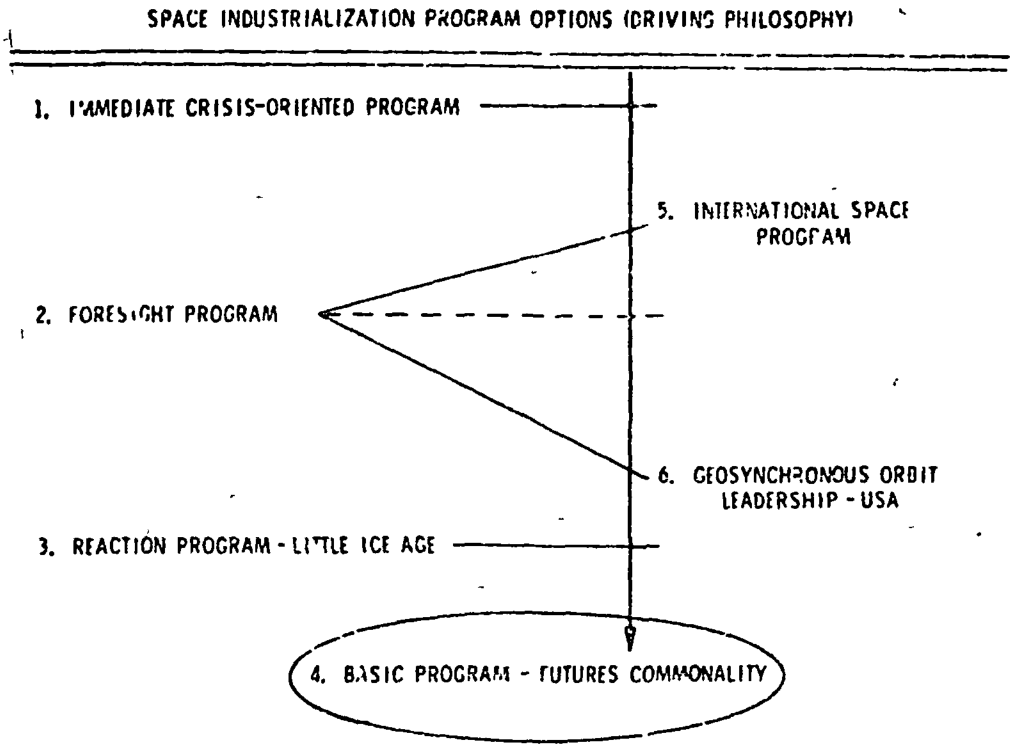

THIS PHILOSOPHY CALLS FOR A PLAY-IT-SAFE APPROACH THAT WARRANTS A REASONABLE INVESTMENT IN SPACE ACTIVITIES THAT ARE COMMON TO THE BASIC FUTURES IDENTIFIED. IT IS NOT STRICTLY NATIONALISTIC, BUT INTERNATIONAL ASSISTANCE IS SECONDARY IN PRIORITY SINCE THE CRISIS INFLUENCES OF FUTURES 1 AND 3 ARE STRONG INFLUENCES.

LEGEND

1 Research and development supported at low levels to gain basic understanding

2. Moderately expanding funds for existing projects Most problems addressed sequentially

3. Funding levels ample, but below accelerated level Expansions according to needs Most problems addressed concurrently

4 Availability of funds is not a limiting factor New programs started according to needs and carried concurrently

5 High national priority assigned to all programs Technology limitations are the only pacesetters.

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The circles indicate importance level, i e , it should definitely be done If the number is not circled, it is still in the program, but is questionable or more subject to cost and schedule compromise Blank spaces across the whole time span indicate that it would be done only if it comes very cheaply as an add-on to a more important item Beyond the last number in the sequence the activity is continuing at a routine level (like weather pictures from space) The program drivers are indicated with stars --- either a combination of importance and rate or of major importance in that particular program option

Figure 5. Basic Program—Futures Commonality

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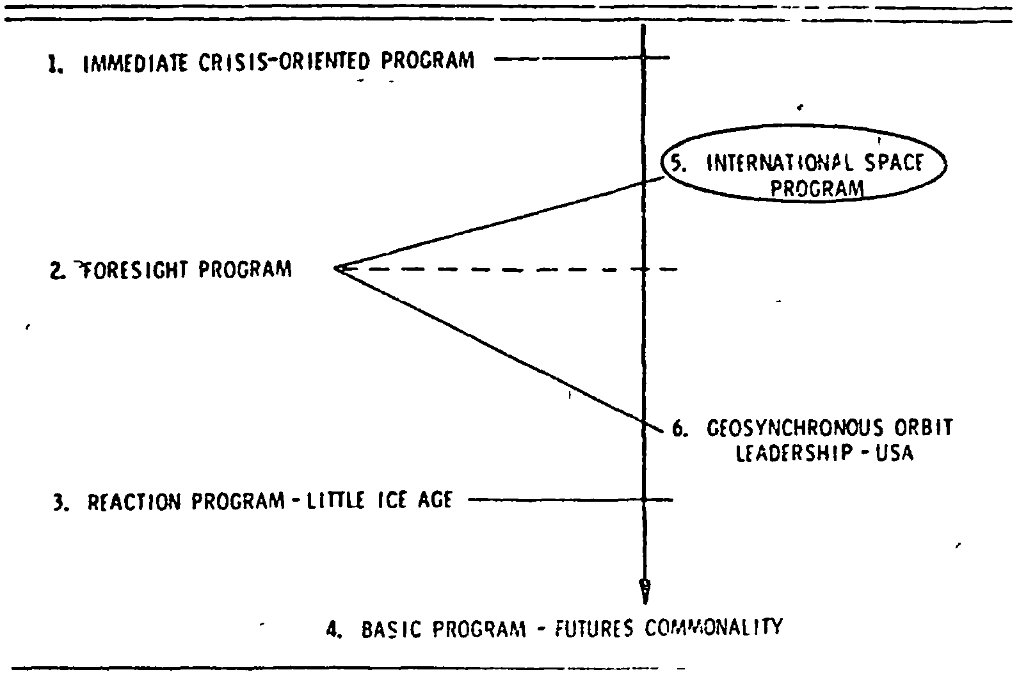
Rockwell International
Space Division

4. BASIC PROGRAM — FUTURES COMMONALITY

Area	Group	No.	Anchor Opportunities / Time Frame	80-85	85-90	90-95	95-10	10-25	No.	Comments
SERVICES	Transmission	☆1	Direct Broadcast Education — U.S.	3	4				1	All of the futures place heavy emphasis on the electronic services. Particular stress is placed on education broadcasts and medical aid and information.
		☆2	Direct Broadcast Education — Devel. Countries	3	3				2	
		3	Business System Data Transfer	3	P				3	
		☆4	Electronic Telecommuting	4	4				4	
		5	World Medical Advice Center	3	3	3			5	
		6	Time and Navigation Services		3	3			6	
		7	Implanted Sensor Data Collector	3	3				7	
		8	National Information Services		3				8	
		9	Personal Communications		3				9	
		10	Electronic Mail (Excl Packages)		3				10	
		☆11	Medical Aid and Information — U S	3	4				11	
		12	Teleoperation From Space						12	
	Observation	☆1	Oil/Mineral Location	3	4				1	Global observation and climate/weather understanding is important in all program options. However, the push to GSO is diminished in the commonality option.
		☆2	Crop Measurement	3	4				2	
		3	~~Oil Spill Detection~~						3	
		☆4	Ocean Resources and Dynamic System	3	4				4	
		☆5	Water Resource Map and Runoff Forecast	3	4				5	
		6	~~Offshore Control Limit Monitoring~~						6	
		☆7	Global Effects Monitoring (STO)	3	4				7	
		8	High Resolution Earth Mapping	3	3				8	
		9	High Resolution Thermal Mapping		2				9	
PRODUCTS	Organic	1	Isoenzymes (Medical Diagnostic Tool)	2	3	3			1	In the products area most of the emphasis is placed on those products which are useful for medical applications or in the electronics industries.
		2	Urokinase (Anticoagulant)	?	3				2	
		3	Insulin (From Human Sources)						3	
	Inorganic	1	Large Crystals (Size and Perfection)						1	
		2	Super Large Scale Integrated Circuits	3					2	
		3	New Glasses (Including Fiber Optics)						3	
		4	High Temperature Turbine Blades						4	
		5	High Strength Permanent Magnets						5	
		6	Thin Film Electronic Devices	2					6	
		7	Continuous Ribbon Crystal Growth						7	
ENERGY	Lunetta	1	Night Illumination for Urban Areas	2	DECISION POINT				1	All of the futures include some large-scale energy systems - either Soletta, SPS or fusion in space. Early experiments will reveal which option will be the most attractive.
		2	Night Illumination for Agric and Indust Ops	2					2	
	Soletta	1	Night Frost Damage Protection	2					1	
		2	Local Climate Manipulation	2					2	
		3	Stimulation of Photosynthesis Process	2					3	
		4	Reflected Light for Ground Elect Conv	2					4	
	SPS	1	Satellite Power System (Solar)	2					1	
		2	Fusion Power Source for MW	2					2	
	In Space	1	Fusion In Space (Research & Operational)	2					1	
HUMAN ACTIVITIES		1	Medical Research Facility (Biosatellite)	2					1	Although man-in-space is necessary for each program, medical research is the only specific opportunity which survives in the human activities area. He goes to GSO early or becomes a large community only in particular programs.
		2	Space Vacation Cruises (Shuttle Mod)						2	
		3	Medical Lab and Facility for Space Personnel						3	
		4	Orbital Tourist Facility						4	
		5	Orbital Hospital (Special Low-g Transport)						5	
		6	Lunar Tourism						6	
LUNAR INDUSTRY		1	Lunar Unmanned Exploration	1	2				1	The pace of lunar exploitation will be determined by the decisions that are made in the energy area.
		2	Lunar Space Station (Manned)		2	3			2	
		3	Lunar Ground Base (Test, Trans Devel, etc)						3	
		4	Lunar Oxygen Industry Establishment			3			4	
		5	Lunar Metal Industry Facilities				4		5	
		6	Lunar Orbiting Factory				3		6	
		7	Lunar Ecosphere (Lunar Agriculture)				3		7	
		8	Large Lunar Industrial Zone						8	

Figure 5. Basic Program—Futures Commonality (Cont.)

SPACE INDUSTRIALIZATION PROGRAM OPTIONS (DRIVING PHILOSOPHY)



THE DRIVING PHILOSOPHY IN THIS PROGRAM OPTION IS THAT FULL WORLD PARTICIPATION IN SPACE ACTIVITIES WILL TEND TO EASE FRICTION AND FOSTER WORLD PEACE. A PRESS TO HAVE ALL COUNTRIES PARTICIPATE AND SHARE THE BENEFITS TENDS TO OVERRIDE PURELY TECHNICAL AND BUSINESS CONSIDERATIONS.

LEGEND

1 Research and development supported at low levels to gain basic understanding

2 Moderately expanding funds for existing projects. Most problems addressed sequentially

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P = Private. The private sector has taken over the effort

The circles indicate importance level, i.e., it should definitely be done. If the number is not circled, it is still in the program, but is questionable or more subject to cost and schedule compromise. Blank spaces across the whole time span indicate that it would be done only if it comes very cheaply as an add-on to a more important item. Beyond the last number in the sequence the activity is continuing at a routine level (like weather pictures from space). The program thrusts are indicated with stars --- either a combination of importance and rate or of major importance in that particular program option.

Figure 6. International Space Program

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Space Division

5. INTERNATIONAL SPACE PROGRAM

			Anchor Opportunities / Time Frame	80-85	85-90	90-95	95 10	10 25	
SERVICES	Transmission	☆1	Direct Broadcast Education – U S	3	3				1
		☆2	Direct Broadcast Education – Devel Countries	3	3				2
		3	Business System Data Transfer	2	3				3
		☆4	Electronic Telecommuting	4	4				4
		☆5	World Medical Advice Center	2	4				5
		6	Time and Navigation Services	3	3				6
		7	Implanted Sensor Data Collector	3	3				7
		8	National Information Services	2	2	3			8
		9	Personal Communications	2	2	3			9
		10	Electronic Mail (Excl Packages)	2	2	3			10
		☆11	Medical Aid and Information – U S	3	4				11
		12	Teleoperation From Space						12
	Observation	☆1	Oil/Mineral Location	4	4				1
		☆2	Crop Measurement	4	4				2
		3	~~Oil Spill Detection~~						3
		☆4	Ocean Resources and Dynamic System	4	4				4
		☆5	Water Resource Map and Runoff Forecast	4	4				5
		6	~~Offshore Control Limit Monitoring~~						6
		☆7	Global Effects Monitoring (STO)	3	4				7
		☆8	High Resolution Earth Mapping	4	4				8
		9	High Resolution Thermal Mapping	3	3				9
PRODUCTS	Organic	☆1	Isoenzymes (Medical Diagnostic Tool)	2	3	P			1
		2	Urokinase (Anticoagulant)	2	P				2
		3	Insulin (From Human Sources)	2	P				3
	Inorganic	1	Large Crystals (Size and Perfection)						1
		☆2	Super Large Scale Integrated Circuits	3	4				2
		3	New Glasses (Including Fiber Optics)						3
		4	High Temperature Turbine Blades						4
		5	High Strength Permanent Magnets						5
		☆6	Thin Film Electronic Devices	3	4	P			6
		7	Continuous Ribbon Crystal Growth						7
ENERGY	Lunetta	☆1	Night Illumination for Urban Areas	3	4	4			1
		☆2	Night Illumination for Agric and Indust Ops	3	4	4			2
	Soletta	☆1	Night Frost Damage Protection	1	2	3	4	4	1
		2	Local Climate Manipulation	1	2	2	3	3	2
		3	Stimulation of Photosynthesis Process	1	2	2	3	3	3
		4	Reflected Light for Ground Elect. Conv.						4
	SPS	☆1	Satellite Power System (Solar)	2	3				1
		2	Fusion Power Source for MW	2	3	4	4	3	2
	In Space	☆1	Fusion In Space (Research & Operational)	2	3	4	4	4	1
HUMAN ACTIVITIES		☆1	Medical Research Facility (Biosatellite)	3	4				1
		2	Space Vacation Cruises (Shuttle Mod)	1	2	3			2
		3	Medical Lab and Facility for Space Personnel	2	4	4			3
		4	Orbital Tourist Facility	1	1	2	3	3	4
		5	Orbital Hospital (Special Low-g Transport)	1	2	3	4	4	5
		6	Lunar Tourism	1	1	1	2	3	6
LUNAR INDUSTRY		1	Lunar Unmanned Exploration	1	3		–		1
		2	Lunar Space Station (Manned)	1	2	4			2
		3	Lunar Ground Base (Test, Trans Devel, etc)	1	2	3	4		3
		4	Lunar Oxygen Industry Establishment		1	2	4		4
		5	Lunar Metal Industry Facilities		1	2	2	4	5
		6	Lunar Orbiting Factory		1	2	2	4	6
		7	Lunar Ecosphere (Lunar Agriculture)		1	2	3	3	7
		8	Large Lunar Industrial Zone						8

The prevention of war should be perhaps the major objective of mankind. Although the complexities of this objective are gargantuan two space related aspects are both true and widely believed (1) the creation of wealth rather than the organization of scarcity moves toward peace and (2) from the vantage point of space, the political boundries and diversities end to disappear and the one world viewpoint matures Many of the services opportunities are excellent candidates for international cooperation, and even more important, are one of the quickest ways that substantial improvements in quality-of-life can be made in developing countries without the successive steps of infrastructure (like roads schools, etc) that developed countries already enjoy Space, via data transmission services directly to/from the user can be very quickly accomplished Thus most of the anchor opportunities shown benefit both types of countries, essentially with the same technology

This is the key area for the program option The services provided are both immediately needed and, as Landsat is showing can be done well via space The opportunities relate to location of the world's resources, management of food and water cooperative movement into the ocean and arctic frontiers and the extremely important subject of understanding the earth s weather and climate so that both short-term weather forecasts and long term climate trends become world-wide, reliable realities

In this program option, those products that support the key services discussed above are important, but are not the program drivers The improvements in electronic devices that appear feasible from space processing will enhance the capabilities of both the space and ground segments of beneficial systems. In addition, medical products have universal appeal and applicability to all mankind

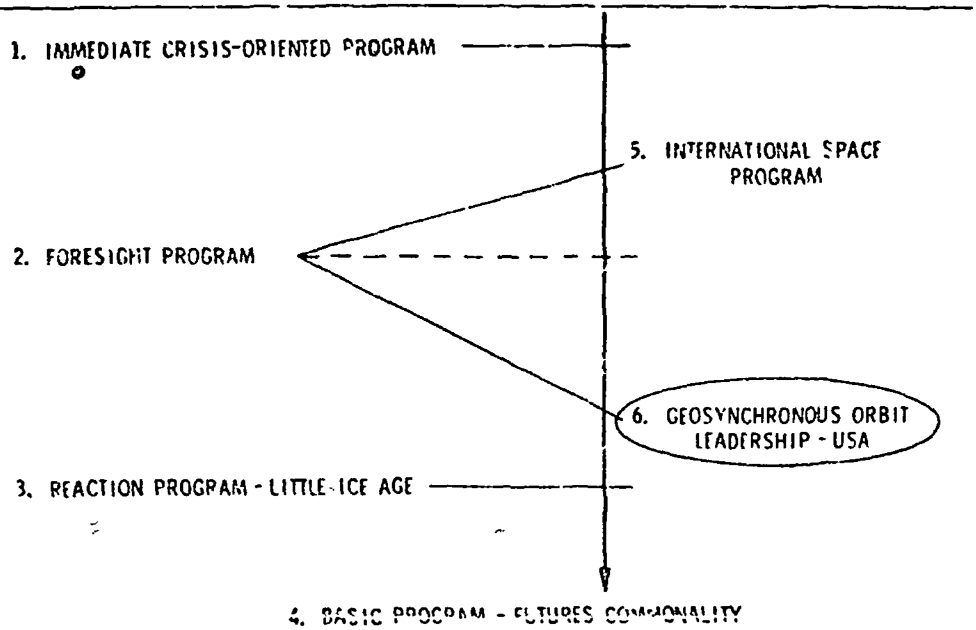
Energy is a world-wide problem more critical to some developing countries and to West Germany and Japan than it is even to the U S However, major long-range solutions, either fusion or solar power are major capital investments with long development and testing sequences. As stepping stones toward operational Solar Power Systems or Solettas Lunettas both develop large structures technology and provide useful light Fusion research and possibly fusion power production in space also fit the category of major investment but awesome pay off These programs are of a type that full world participation is perhaps warranted and nearly full world benefit is assured if successful In any case a decision point comes in about 1990 to either count on fusion or accelerate SPS

The International philosophy tends to support human activities in space but not as the main thrust certainly if SPS's or Solettas are to be eventually built the basis for large numbers of people living and working in space should be well founded In addition, the personal thrill of being in space may have universal appeal to many people including world leaders

As in other program options lunar industry supports large orbital facilities in GSO such as SPS or Soletta In addition in this particular program option international utilization of lunar resources removes a source of conflict developed countries may vie for position while developing countries want the moon left undisturbed unless they can see a resulting benefit to them

Figure 6. International Space Program (Cont.)

SPACE INDUSTRIALIZATION PROGRAM OPTIONS (DRIVING PHILOSOPHY)



THE FUNDAMENTAL DRIVER IN THIS OPTION IS TO MOVE QUICKLY TOWARD THE GOAL OF PUTTING U.S. MACHINERY AND, EVENTUALLY, CITIZENS IN THE THREE OR FOUR MOST STRATEGIC GSO POSITIONS, WORLD WIDE, IN ORDER TO TEND TO CONTROL (AND KEEP AHEAD OF COMPETITION) THE SERVICES THAT ARE INDUSTRIAL OPPORTUNITIES IN THESE LOCATIONS. THE ORDER OF PRIORITY IS (1) CONTINENTAL UNITED STATES, (2) CONNECTING THE UNITED STATES AND EUROPE, (3) CONNECTING THE UNITED STATES AND THE FAR EAST, AND (4) ASIA SUBTLE EXCLUSION OF OTHERS WOULD BE BY CONSISTENT TECHNICAL SUPERIORITY AND TRANSPORTATION SYSTEMS

LEGEND

1 Research and development supported at low levels to gain basic understanding

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Figure 7. Geosynchronous Orbiter Leadership—USA

Rockwell International

Space Division

6. GEOSYNCHRONOUS ORBIT LEADERSHIP – USA

Category	Group	No.	Anchor Opportunities / Time Frame	80-85	85-90	90 95	95-10	10-25	No.
SERVICES	Transmission	☆1	Direct Broadcast Education – U S.	3	4				1
		☆2	Direct Broadcast Education – Devel. Countries	3	4				2
		3	Business System Data Transfer	3	P				3
		☆4	Electronic Telecommuting	4	4				4
		☆5	World Medical Advice Center	2	3	4			5
		6	Time and Navigation Services	2	2	3			6
		7	Implanted Sensor Data Collector	2	3	3			7
		8	National Information Services	2	3	3			8
		☆9	Personal Communications	2	4				9
		10	Electronic Mail (Excl Packages)	2	3	3			10
		☆11	Medical Aid and Information – U S.	3	4				11
		12	Teleoperation From Space						12
	Observation	1	Oil/Mineral Location	2	3				1
		2	Crop Measurement	2	3	3			2
		3	~~Oil Spill Detection~~						3
		4	Ocean Resources and Dynamic System	2	3				4
		5	Water Resource Map and Runoff Forecast	3	3				5
		6	~~Offshore Control Limit Monitoring~~						6
		☆7	Global Effects Monitoring (STO)	3	4	4			7
		8	High-Resolution Earth Mapping	2	3	3			8
		9	High Resolution Thermal Mapping	2	2	2			9

The information transmission services represent a huge future market open to whoever captures the lead and holds it. Certainly the USA is capable of this. The thought here is not based primarily on stable positions but rather continuing presence and technological leadership such as was enjoyed by the U S commercial air transport business during the last two decades. In this option the transmission services are integrated into relatively few, very capable spacecraft. Man is introduced into the GSO scene relatively quickly to add reliability, flexibility, capability and assurance against obsolescence. Government investment in initial systems and transportation systems (particularly in or-orbital) is heavily supplemented by U S industry consortiums. Education from space and electronic telecommunicating lead the requirements, but most other services that make sense (and money) follow along since the technology and systems that can do No 1 and No 4 can do most of the others at little additional cost to the space segment of the overall system.

In this option, the observation services lead first toward high inclination orbits and only later to GSO. The main exception is Global Effects Monitoring, which includes the Solar Terrestrial Observatory. This has a manned base in GSO and would be a program driver (along with information transmission) in configuring the GSO system.

Category	Group	No.	Anchor Opportunities	80-85	85-90	90 95	95-10	10-25	No.
PRODUCTS	Organic	1	Isoenzymes (Medical Diagnostic Tool)	1	2	P			1
		2	Urokinase (Anticoagulant)	2	2	P			2
		3	Insulin (From Human Sources)	1	2	P			3
	Inorganic	1	Large Crystals (Size and Perfection)						1
		☆2	Super Large Scale Integrated Circuits	3	4	P			2
		3	New Glasses (Including Fiber Optics)						3
		4	High Temperature Turbine Blades						4
		5	High Strength Permanent Magnets						5
		☆6	Thin Film Electronic Devices	3	4	P			6
		7	Continuous Ribbon Crystal Growth						7

Products do not directly support the philosophy of this program option. In an indirect sense, however, electronic advances are an integral part of the overall plan. Also, regardless of the main thrust of the program option those products that Shuttle/Spacelab show to be valid should (and will) be done on an industrial scale in low orbits.

Category	Group	No.	Anchor Opportunities	80-85	85-90	90 95	95-10	10-25	No.
ENERGY	Lunetta	1	Night Illumination for Urban Areas						1
		2	Night Illumination for Agric and Indust. Ops						2
	Soletta	1	Night Frost Damage Protection						1
		2	Local Climate Manipulation						2
		3	Stimulation of Photosynthesis Process						3
		4	Reflected Light for Ground Elect Conv.						4
	MW	☆1	Satellite Power System (Solar)	2	4	4	4	4	1
		2	Fusion Power Source for MW						2
	In Space	1	Fusion In Space (Research & Operational)					1	1

SPS's lead toward GSO capability. Thus, in addition to its intrinsic worth, it supports the philosophy of this program option.

Category	No.	Anchor Opportunities	80-85	85-90	90 95	95-10	10-25	No.
HUMAN ACTIVITIES	1	Medical Research Facility (Biosatellite)	3					1
	2	Space Vacation Cruises (Shuttle Mod)						2
	3	Medical Lab and Facility for Space Personnel	2	4	4			3
	4	Orbital Tourist Facility						4
	5	Orbital Hospital (Special Low-g Transport)						5
	6	Lunar Tourism						6

Human activities in this option are primarily those that develop the technical base for large numbers of people in GSO for reasons discussed above.

Category	No.	Anchor Opportunities	80-85	85-90	90 95	95-10	10-25	No.
LUNAR INDUSTRY	1	Lunar Unmanned Exploration	1	3				1
	2	Lunar Space Station (Manned)	1	2	4			2
	3	Lunar Ground Base (Test, Trans Devel, etc)	1	2	4			3
	4	Lunar Oxygen Industry Establishment		1	2	4	4	4
	5	Lunar Metal Industry Facilities		1	2	2	3	5
	6	Lunar Orbiting Factory		1	2	2	3	6
	7	Lunar Ecosphere (Lunar Agriculture)		1	2	3	3	7
	8	Large Lunar Industrial Zone						8

Lunar industry in this program option is primarily in response to SPS and Soletta requirements.

Figure 7. Geosynchronous Orbiter Leadership—USA (Cont.)

ALTERNATIVE PROGRAM PLANS

ALTERNATIVE PROGRAM PLANS

In Part 1 of the *Space Industrialization* study, the two contractors (Rockwell International and Science Applications, Inc.) worked separately without consultation or coordination of results. The purpose of this approach was to obtain two separate sets of recommendations from two different points of view. As it turned out, the recommendations were surprisingly similar. In particular, both contractors advocated leading with services (called information in SAI reports), but including products (materials), energy, and human activities (people).

A different philosophy was followed in Part 2. In this segment of the study constant coordination and integration was actively encouraged. Hence, for example, Part 2 began with a two-day boiler-room session at Seal Beach with participants from both contractors and representatives from NASA. As an outcome of this first task a selected set of program options (which are really alternative *space industrialization* plans) were derived. Figure 8 summarizes the basic philosophy of the three plans. Plan A is the most ambitious of the three. It is based on the assumption that Satellite Power System will be a reality, with many units produced for operation around the year 2000. Within Plan A is Plan A1 which uses lunar materials extensively in SPS transportation and construction. In Plan A2 terrestrial materials are used exclusively in the construction of the SPS.

Plan B assumes that SPS will be developed toward a 1987 decision point, but will not proceed to operational status. In this plan, the technology applicable to SPS (large structures, large power generation in space, etc.) is available for other *space industrialization* opportunities. The design approach to hardware implementation of the opportunities is largely influenced by the SPS design and, of course, the cost of the technology development attributable to non-SPS activities is shared by SPS funding.

Plan C assumes that SPS will not be pursued beyond 1982 and, hence, the other opportunities must stand more on their own technology base. This, in turn, means that they are more nearly optimized toward their own needs.

As Figure 9 shows, the three plans were an outgrowth of both Rockwell and SAI Part 1 work, but emphasizing the SPS influence. In each of the plans the product and service opportunities that were endorsed by both contractors at the end of Part 1 make up the anchor opportunities. (More products can probably be developed at very little delta cost, so these are representative products rather than being all inclusive.)

In summary, these new *space industrialization* plans recognize that SPS dominates the technology requirements and will basically dictate the approach to hardware design if SPS is accomplished on a time scale leading to a first operational unit in 1995. However, a thriving *space industrialization* program should occur even without SPS since the other *space industrialization* opportunities have enough merit that they easily stand on their own economic merit and pay back the investments required.

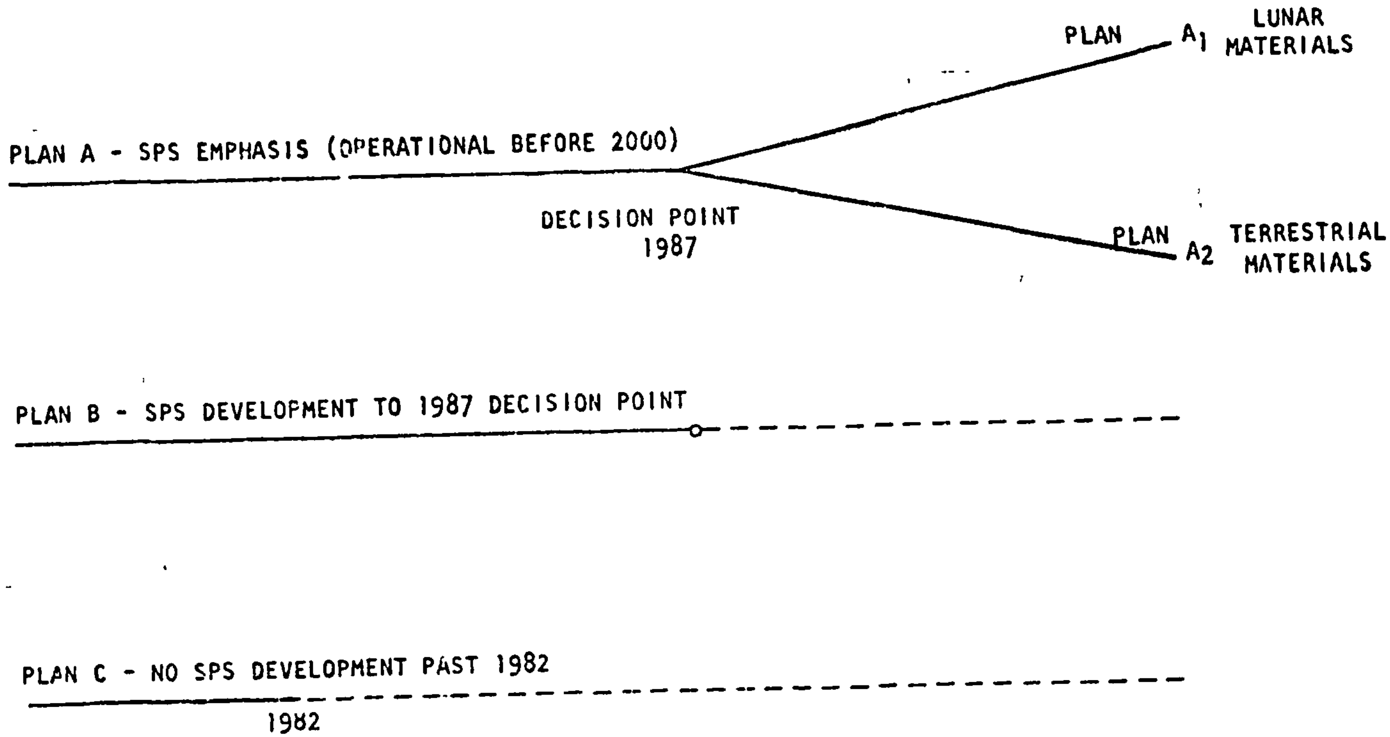

Figure 8. Space Industrialization Part 2 Alternative Plans

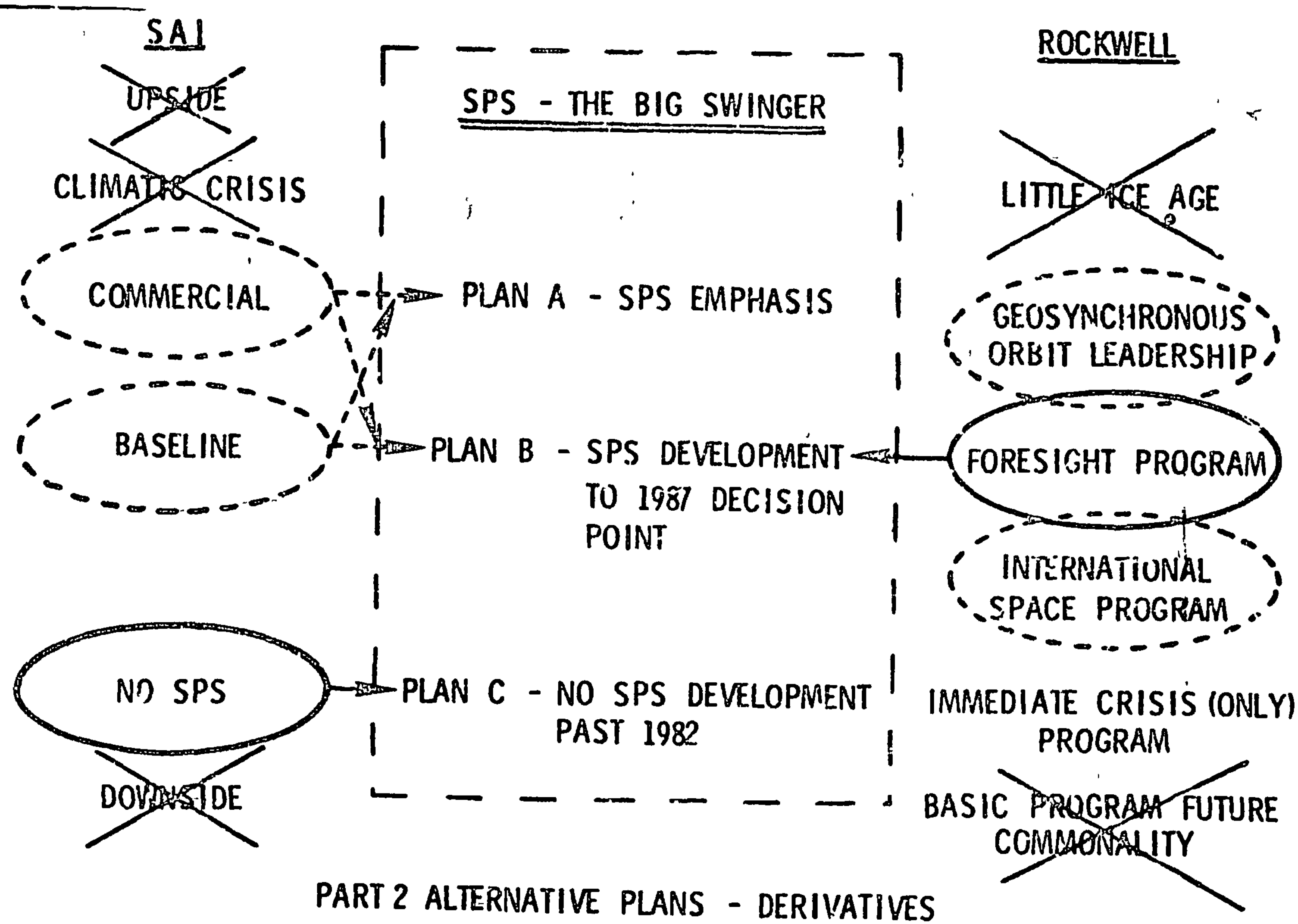

Figure-9. Part 2 Alternative Plans—Derivatives

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Individual definitions of Plans A_1, A_2, B, and C are presented in Figures 10 through 13. These definitions are similar to those presented in Figures 2 through 7; however, they are laid out in a slightly different way and the symbols have been simplified to a significant degree. The symbols in the figures are to be interpreted in accordance with the following code:

R = Research

D = Development

O = Operational

O' = A step change in the operational facilities

O'' = Another step change in the operational facilities

A comparison between these figures and the ones that appeared previously shows certain striking similarities. However, the two sets of charts are not meant to be identical. This is primarily because Figures 10 through 13 were constructed at a different point in time, under the influence of a fuller knowledge base, and in a cooperative manner with the help of SAI and the NASA contract monitors.

A careful study of the symbols in Figures 10 through 13 clearly reveals the strong influence of the decision on whether or not to build the SPS. In particular, an early positive decision on the SPS will lead to large scale upgrading of our transportation hardware and to a greater concentration on manned space operations. In addition, a positive SPS decision results in an earlier development of many unrelated hardware elements, particularly those that utilize large space structures. On the other hand (as is shown in Figures 10 through 13), the deletion of the SPS even in an early time frame does not result in a total devastation of the U.S. Space Program. There are many activities that will pay broad dividends in their own right whether or not SPS becomes a reality before we pass into the 21st century.

ANCHOR OPPORTUNITIES	TIME FRAME 80-85	85-90	90-95	95-00	00-10
TRANSMISSION					
DIRECT-BROADCAST EDUCATION - U.S.	O	O'	O''		
DIRECT-BROADCAST EDUCATION - DEVEL. COUNTRIES	D	O		O'	O''
BUSINESS SYSTEM DATA TRANSFER	O	O'	O''		
ELECTRONIC TELECOMMUTING	R	D	O		
ELECTRONIC TELECONFERENCING	D	O			O'
WORLD MEDICAL ADVICE CENTER	D	O	O'		
TIME AND NAVIGATION SERVICES	O				
IMPLANTED SENSOR DATA COLLECTOR	D	O	O'	O''	
NATIONAL INFORMATION SERVICES			D	O	
PERSONAL COMMUNICATIONS	D	O	O'		
ELECTRONIC MAIL (EXCL. PACKAGES)	D	O	O'	O''	
MEDICAL AID AND INFORMATION - U.S.	D	O			
TELEOPERATION FROM SPACE			R	D	O
OBSERVATION					
OIL/MINERAL LOCATION	O			O'	
CROP MEASUREMENT	D	O	O'		
OCEAN RESOURCES AND DYNAMIC SYSTEM	D	O			
WATER RESOURCE MAP AND RUNOFF FORECAST	O				
GLOBAL EFFECTS MONITORING (STO)	O	O	O'	O''	
LANDSAT D	O				
TOPOGRAPHIC MAPPING	D	O			
HIGH-RESOLUTION RESOURCE SURVEY	D	O			
HIGH-RESOLUTION RADAR MAPPING	R	D	O		

Figure 10. Plan A_1 - SPS Emphasis - Lunar Material

Figure 10. Plan A_1 - SPS Emphasis - Lunar Material (Continued)

ANCHOR OPPORTUNITIES	TIME FRAME				
	80-85	85-90	90-95	95-00	00-10
PRODUCTS					
ORGANIC					
ISOZYMES (ALSO MEDICAL DIAGNOSTIC)	R	O			
UROKINASE (ANTICOAGULANT)	D	O			
INSULIN (FROM HUMAN SOURCES)	D	O			
INORGANIC					
LARGE CRYSTALS (SIZE AND PERFECTION)	O				
SUPER-LARGE-SCALE INTEGRATED CIRCUITS	O	O'		O''	
NEW GLASSES (INCLUDING FIBER OPTICS)	D	O	O'	O''	
HIGH-TEMPERATURE TURBINE BLADES	D	O	O'		
HIGH-STRENGTH PERMANENT MAGNETS	O				
CUTTING TOOLS	D	O		O'	
THIN-FILM ELECTRONIC DEVICES	D	O	O'		
CONTINUOUS RIBBON CRYSTAL GROWTH	D	O			
ENERGY					
LUNETTA					
NIGHT ILLUMINATION FOR URBAN AREAS	R	D	O	O'	
NIGHT ILLUMINATION FOR AGR & INDUST OPERATIONS			O		
SOLETTA					
NIGHT FROST DAMAGE PROTECTION			D	O	
REFLECTED LIGHT FOR GROUND-ELECT. CONV.	R	R			
MW					
SATELLITE POWER SYSTEM (SOLAR)	R	D	D	O	O'
FUSION IN SPACE	R	R	D	D	O

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Figure 10. Plan A_1 - SPS Emphasis - Lunar Material (Continued)

ANCHOR OPPORTUNITIES	TIME FRAME 80-85	85-90	90-95	95-00	00-10
HUMAN ACTIVITIES					
MEDICAL AND GENETIC RESEARCH	D	O			
SPACE VACATION CRUISES (SHUTTLE FLIGHTS)			D	O	
ORBITAL TOURISM (LEO HOTEL)			R	D	O
ORBITAL THERAPEUTICS				D	O
ENTERTAINMENT AND ARTS			O		
LUNAR					
UNMANNED EXPLORERS	D	O			
LUNAR ORBITER		D	O		
LUNAR BASE		R	D	O	
LUNAR INDUSTRY		R	D	O	
SUPPORT ELEMENTS					
FUNCTIONAL					
SHUTTLE/SPACELAB	O				
LANDSATS/SEASATS	O		O'		
COMSATS	O	O'			
PUBLIC SERVICE PLATFORM	D/O	O	O'	O'	O'
LEO BASE + PROPELLANT DEPOT	D	O-	-O'		
GLOBAL WEATHER AND RESOURCE BASE	D	O		O'	
LUNETTA (DEMONSTRATION)	D	O			
SPS	R	D	D	O	O'
POWERSOLETTA	R	R			
TELEOPERATOR (GSO)	O		O'		
TRANSPORTATION					
SHUTTLE & IUS/SSUS	O				
HLLV (SHUTTLE WITHOUT ORBITER)	D	O			
LOW-THRUST OTV SEPS (OR CHEMICAL)	D/O			O'	
OTV (LARGE CHEMICAL)	R	D	O		
MOTV (FROM ABOVE)	R	D	O		
HLLV-II (SPS SIZE)	R	D	O		
CISLUNAR TRANSPORT		R	D	O	
LUNAR ORBIT/SURFACE SHUTTLE		R	D	O	

Rockwell International
Space Division

ANCHOR OPPORTUNITIES	TIME FRAME 80-85	85-90	90-95	95-00	00-10
TRANSMISSION					
DIRECT-BROADCAST EDUCATION - U.S.	O	O'	O''		
DIRECT-BROADCAST EDUCATION - DEVEL. COUNTRIES	D	O		O'	O''
BUSINESS SYSTEM DATA TRANSFER	O	O'	O''		
ELECTRONIC TELECOMMUTING	R	D	O		
ELECTRONIC TELECONFERENCING	D	O			O'
WORLD MEDICAL ADVICE CENTER	D	O	O'		
TIME AND NAVIGATION SERVICES	O				
IMPLANTED SENSOR DATA COLLECTOR	D	O	O'	O''	
NATIONAL INFORMATION SERVICES			D	O	
PERSONAL COMMUNICATIONS	D	O	O'		
ELECTRONIC MAIL (EXCL. PACKAGES)	D	O	O'	O''	
MEDICAL AID AND INFORMATION - U.S.	D	O			
TELEOPERATION FROM SPACE			R	D	O
OBSERVATION					
OIL/MINERAL LOCATION	O			O'	
CROP MEASUREMENT	D	O	O'		
OCEAN RESOURCES AND DYNAMIC SYSTEM	D	O			
WATER RESOURCE MAP AND RUNOFF FORECAST	O				
GLOBAL EFFECTS MONITORING (STO)	O	O	O'	O''	
LANDSAT D	O				
TOPOGRAPHIC MAPPING	D	O			
HIGH-RESOLUTION RESOURCE SURVEY	D	O			
HIGH-RESOLUTION RADAR MAPPING	R	D	O		

Figure 11. Plan A_2 - SPS Emphasis - Terrestrial Materials

Figure 11. Plan A_2 - SPS Emphasis - Terrestrial Materials (Continued)

ANCHOR OPPORTUNITIES	TIME FRAME 80-85	85-90	90-95	95-00	00-10
PRODUCTS					
ORGANIC					
ISOZYMES (ALSO MEDICAL DIAGNOSTIC)	R	0			
UROKINASE (ANTICOAGULANT)	D	0			
INSULIN (FROM HUMAN SOURCES)	D	0			
INORGANIC					
LARGE CRYSTALS (SIZE AND PERFECTION)	0				
SUPER-LARGE-SCALE INTEGRATED CIRCUITS	0	0'		0''	
NEW GLASSES (INCLUDING FIBER OPTICS)	D	0	0'	0''	
HIGH-TEMPERATURE TURBINE BLADES	D	0	0'		
HIGH-STRENGTH PERMANENT MAGNETS	0				
CUTTING TOOLS	D	0		0'	
THIN-FILM ELECTRONIC DEVICES	D	0	0'		
CONTINUOUS RIBBON CRYSTAL GROWTH	D	0			
ENERGY					
LUNETTA					
NIGHT ILLUMINATION FOR URBAN AREAS	R	D	0	0'	
NIGHT ILLUMINATION FOR AGR & INDUST OPERATIONS			0		
SOLETTA					
NIGHT FROST DAMAGE PROTECTION			D	0	
REFLECTED LIGHT FOR GROUND-ELECT. CONV.	R	R			
MW					
SATELLITE POWER SYSTEM (SOLAR)	R	D	D	0	0'
FUSION IN SPACE	R	R	D	D	0

Figure 11. Plan A_2 - SPS Emphasis - Terrestrial Materials (Continued)

ANCHOR OPPORTUNITIES	TIME FRAME 80-85	85-90	90-95	95-00	00-10
HUMAN ACTIVITIES					
MEDICAL AND GENETIC RESEARCH	D	O			
SPACE VACATION CRUISES (SHUTTLE FLIGHTS)			D	O	
ORBITAL TOURISM (LEO HOTEL)			R	D	O
ORBITAL THERAPEUTICS				D	O
ENTERTAINMENT AND ARTS			O		
LUNAR					
UNMANNED EXPLORERS	D	O			
LUNAR ORBITER		D	O		
LUNAR BASE			R	D	O
LUNAR INDUSTRY					
SUPPORT ELEMENTS					
FUNCTIONAL					
SHUTTLE/SPACELAB	O				
LANDSATS/SEASATS	O		O'		
COMSATS	O	O'			
PUBLIC SERVICE PLATFORM	D/O	O	O'	O'	O'
LEO BASE + PROPELLANT DEPOT	D	O	O'		
GLOBAL WEATHER AND RESOURCE BASE	D	O		O'	
LUNETTA (DEMONSTRATION)	D	O			
SPS	R	D	D	O	O'
POWERSOLETTA	R	R			
TELEOPERATOR (GSO)	O		O'		
TRANSPORTATION					
SHUTTLE & IUS/SSUS	O				
HLLV (SHUTTLE WITHOUT ORBITER)	D	O			
LOW-THRUST OTV (SEPS OR CHEMICAL)	D/O			O'	
OTV (LARGE CHEMICAL)	R	D	O		
MOTV (FROM ABOVE)	R	D	O		
HLLV-II (SPS SIZE)	R	D	O		
CISLUNAR TRANSPORT			R	D	O
LUNAR ORBIT/SURFACE SHUTTLE			R	D	O

Rockwell International
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ANCHOR OPPORTUNITIES	TIME FRAME 80-85	85-90	90-95	95-00	00-10
TRANSMISSION					
DIRECT-BROADCAST EDUCATION - U.S.	O	O'	O''	→	→
DIRECT-BROADCAST EDUCATION - DEVEL. COUNTRIES	D	O	→	O'	O''
BUSINESS SYSTEM DATA TRANSFER	O	O'	O''	→	→
ELECTRONIC TELECOMMUTING	R	D	O	→	→
ELECTRONIC TELECONFERENCING	D	O	→	→	O'
WORLD MEDICAL ADVICE CENTER	D	O	O'	→	→
TIME AND NAVIGATION SERVICES	O	→	→	→	→
IMPLANTED SENSOR DATA COLLECTOR	D	O	O'	O''	→
NATIONAL INFORMATION SERVICES			D	O	→
PERSONAL COMMUNICATIONS	D	O	O'	→	→
ELECTRONIC MAIL (EXCL. PACKAGES)	D	O	O'	O''	→
MEDICAL AID AND INFORMATION - U.S.	D	O	→	→	→
TELEOPERATION FROM SPACE			R	D	O
OBSERVATION					
OIL/MINERAL LOCATION	O	→	→	O'	→
CROP MEASUREMENT	D	O	O'	→	→
OCEAN RESOURCES AND DYNAMIC SYSTEM	D	O	→	→	→
WATER RESOURCE MAP AND RUNOFF FORECAST	O	→	→	→	→
GLOBAL EFFECTS MONITORING (STO)	O	O	O'	O''	→
LANDSAT D	O	→	→	→	→
TOPOGRAPHIC MAPPING	D	O	→	→	→
HIGH-RESOLUTION RESOURCE SURVEY	D	O	→	→	→
HIGH-RESOLUTION RADAR MAPPING	R	D	O	→	→

Figure 12. Plan B - SPS Development to 1987 Decision Point (Baseline)

Figure 12. Plan B - SPS Development to 1987 Decision Point (Baseline) (Continued)

ANCHOR OPPORTUNITIES	TIME FRAME 80-85	85-90	90-95	95-00	00-10
PRODUCTS					
ORGANIC					
ISOZYMES (ALSO MEDICAL DIAGNOSTIC)	R	O	→	→	→
UROKINASE (ANTICOAGULANT)	D	O	→	→	→
INSULIN (FROM HUMAN SOURCES)	D	O	→	→	→
INORGANIC					
LARGE CRYSTALS (SIZE AND PERFECTION)	O	→	→	→	→
SUPER-LARGE-SCALE INTEGRATED CIRCUITS	O	D'	→	O''	→
NEW GLASSES (INCLUDING FIBER OPTICS)	D	O	O'	O''	→
HIGH-TEMPERATURE TURBINE BLADES	D	O	O'	→	→
HIGH-STRENGTH PERMANENT MAGNETS	O	→	→	→	→
CUTTING TOOLS	D	O	→	O'	→
THIN-FILM ELECTRONIC DEVICES	D	O	O'	→	→
CONTINUOUS RIBBON CRYSTAL GROWTH	D	O	→	→	→
ENERGY					
LUNETTA					
NIGHT ILLUMINATION FOR URBAN AREAS	R	D	O	→	→
NIGHT ILLUMINATION FOR AGR. & INDUST OPERATIONS			O	→	→
SOLETTA					
NIGHT FROST DAMAGE PROTECTION			R	D	O
REFLECTED LIGHT FOR GROUND-ELECT. CONV.	R	R			
MW					
SATELLITE POWER SYSTEM (SOLAR)	R	R			
FUSION IN SPACE	R	R	D	D	O

Figure 12. Plan B - SPS Development to 1987 Decision Point (Baseline) (Continued)

ANCHOR OPPORTUNITIES	TIME FRAME 80-85	85-90	90-95	95-00	00-10
HUMAN ACTIVITIES					
MEDICAL AND GENETIC RESEARCH	D	O			
SPACE VACATION CRUISES (SHUTTLE FLIGHTS)			D	O	
ORBITAL TOURISM (LEO HOTEL)			R	D	O
ORBITAL THERAPEUTICS				D	O
ENTERTAINMENT AND ARTS			O		
LUNAR					
UNMANNED EXPLORERS	D	O			
LUNAR ORBITER		D	O		
LUNAR BASE (SCIENTIFIC)			R	D	O
LUNAR INDUSTRY					
SUPPORT ELEMENTS					
FUNCTIONAL					
SHUTTLE/SPACELAB	O				
LANDSATS/SEASATS	O		O'		
COMSATS	O	O'			
PUBLIC SERVICE PLATFORM	D/O	O	O'	O'	O'
LEO BASE	D	O		O'	
GLOBAL WEATHER AND RESOURCE BASE	D	O		O	
LUNETTA (DEMONSTRATION)	D	O			
SPS	R	R			
POWERSOLETTA	R	R			
TELEOPERATOR (GSO)	O		O'		
TRANSPORTATION					
SHUTTLE & IUS/SSUS	O		O'		
HLLV (SHUTTLE WITHOUT ORBITER)	D	O		O'	
LOW-THRUST OTV SEPS (OR CHEMICAL)	D/O			O'	
OTV (LARGE CHEMICAL)	R	D	O		
MOTV (FROM ABOVE)		R	D	O	
HLLV-II (SPS SIZE)	R	R			
CISLUNAR TRANSPORT			R	D	O
LUNAR ORBIT/SURFACE SHUTTLE			R	D	O

ANCHOR OPPORTUNITIES	TIME FRAME				
	80-85	85-90	90-95	95-00	00-10
TRANSMISSION					
DIRECT-BROADCAST EDUCATION - U.S.	O	O'	O''		
DIRECT-BROADCAST EDUCATION - DEVEL. COUNTRIES	D	O		O'	O''
BUSINESS SYSTEM DATA TRANSFER	U	O'	O''		
ELECTRONIC TELECOMMUTING	R	D	O		
ELECTRONIC TELECONFERENCING	D	O			O'
WORLD MEDICAL ADVICE CENTER	D	O	O'		
TIME AND NAVIGATION SERVICES	O				
IMPLANTED SENSOR DATA COLLECTOR	D	O	O'	O''	
NATIONAL INFORMATION SERVICES			D	O	
PERSONAL COMMUNICATIONS	D	O	O'		
ELECTRONIC-MAIL (EXCL. PACKAGES)	D	O	O'	O''	
MEDICAL AID AND INFORMATION - U.S.	D	O			
TELEOPERATION FROM SPACE			R	D	O
OBSERVATION					
OIL/MINERAL LOCATION	O			O'	
CROP MEASUREMENT	D	O	O'		
OCEAN RESOURCES AND DYNAMIC SYSTEM	D	O			
WATER RESOURCE MAP AND RUNOFF FORECAST	O				
GLOBAL EFFECTS MONITORING (STO)	O	O	O'	O''	
LANDSAT D	O				
TOPOGRAPHIC MAPPING	D	O			
HIGH-RESOLUTION-RESOURCE SURVEY	D	O			
HIGH-RESOLUTION RADAR MAPPING	R	D	O		

Figure 13. Plan C - No SPS Development Plust 1982

Figure 13. Plan C - No SPS Development Past 1982 (Continued)

ANCHOR OPPORTUNITIES	TIME FRAME 80-85	85-90	90-95	95-00	00-10
PRODUCTS					
ORGANIC					
ISOZYMES (ALSO MEDICAL DIAGNOSTIC)	R	0	→	→	→
UROKINASE (ANTICOAGULANT)	D	0	→	→	→
INSULIN (FROM HUMAN SOURCES)	D	0	→	→	→
INORGANIC					
LARGE CRYSTALS (SIZE AND PERFECTION)	0	→	→	→	→
SUPER-LARGE-SCALE INTEGRATED CIRCUITS	0	0'	→	0''	→
NEW GLASSES (INCLUDING FIBER OPTICS)	D	0	0'	0''	→
HIGH-TEMPERATURE TURBINE BLADES	D	0	0'	→	→
HIGH-STRENGTH PERMANENT MAGNETS	0	→	→	→	→
CUTTING TOOLS	D	0	→	0'	→
THIN-FILM ELECTRONIC DEVICES	D	0	0'	→	→
CONTINUOUS RIBBON CRYSTAL GROWTH	D	0	→	→	→
ENERGY					
LUNETTA					
NIGHT ILLUMINATION FOR URBAN AREAS	R	D	D	0	→
NIGHT ILLUMINATION FOR AGR & INDUST OPERATIONS				0	→
SOLETTA					
NIGHT FROST DAMAGE PROTECTION			R	D	0
REFLECTED LIGHT FOR GROUND-ELECT. CONV.	R	-			
MW					
SATELLITE POWER SYSTEM (SOLAR)	R	-			
FUSION IN SPACE	R	R	D	D	0

Figure 13. Plan C - No SPS Development Past 1982 (Continued)

ANCHOR OPPORTUNITIES	TIME FRAME 80-85	85-90	90-95	95-00	00-10
HUMAN ACTIVITIES					
MEDICAL AND GENETIC RESEARCH	D	O			
SPACE VACATION CRUISES (SHUTTLE FLIGHTS)			D	O	
ORBITAL TOURISM (LEO HOTEL)			R	D	O
ORBITAL THERAPEUTICS				D	O
ENTERTAINMENT AND ARTS			O		
LUNAR					
UNMANNED EXPLORERS	D	O			
LUNAR ORBITER		D	O		
LUNAR BASE (SCIENTIFIC)			R	D	O
LUNAR INDUSTRY					
SUPPORT ELEMENTS					
FUNCTIONAL					
SHUTTLE/SPACELAB	O				
LANDSATS/SEASATS	O		O'		
COMSATS	O	O'			
PUBLIC SERVICE PLATFORM	D/O	O	O'	O'	O'
LEO BASE	D	O		O'	
GLOBAL WEATHER AND RESOURCE BASE	D	O		O	
LUNETTA (DEMONSTRATION)	D	D	O		
SPS	R	-			
POWERSOLETTA	R	-			
TELEOPERATOR (GSO)	O		O'		
TRANSPORTATION					
SHUTTLE & IUS/SSUS	O		O'		
HLLV (SHUTTLE WITHOUT ORBITER)	D	O		O'	
LOW-THRUST OTV SEPS OR CHEMICAL)	D/O			O'	
OTV (LARGE CHEMICAL)	R	D	O		
MOTV (FROM ABOVE)		R	D	O	
HLLV-II (SPS SIZE)	R	-			
CISLUNAR TRANSPORT			R	D	O
LUNAR ORBIT/SURFACE SHUTTLE			R	D	O

Shuttle-Tended and Space Base Facilities
Space Processing Facilities
Geosynchronous Orbit Facilities
High-Inclination Orbit Facilities
SPS Development Activities
Transportation Elements

IMPLEMENTING CONCEPTS—RECOMMENDED PLAN (SPS TECHNOLOGY)

IMPLEMENTING CONCEPTS - RECOMMENDED PLAN (SPS TECHNOLOGY)

The implementing concepts for the envisioned *space industrialization* activities are summarized in Figure 14. These activities correspond to Program Plan A in which the decision point on whether or not to proceed on the SPS development occurs in 1987, after significant developmental programs have taken place. In the years between now and then, we believe that the best overall strategy is to push toward an SPS capability while capitolizing on as many highly visible benefits as possible along the way.

As can be seen, Figure 14 is divided into three time frames — each spanning a 10-year interval. In the first 10-year interval, the center of activity is in low earth orbit and we use the Shuttle to its fullest extent including adding a 25-kw power module that can be left in orbit. We establish a public service platform and a global weather and resources base, both of which provide worldwide benefits. We eventually establish a facility in low earth orbit that is a construction base, a space factory, and space operations center. We learn to build large structures as a step toward SPS and put this to good use as we make multi-hundred kilowatt power modules, and build an operational Lunetta system.

In the second 10-year interval (the 1990's), the capabilities of the space factory, public service platform, the solar terrestrial observatory, and also bring into initial operation a satellite power system (or fusion or Powersoletta). Beyond the year 2000, we utilize the moon to furnish oxygen and materials for massive energy-related projects at the geosynchronous altitude.

The chart also shows transportation additions. The 1980's need only the Shuttle and modifications thereto. A low-thrust inter-orbit propulsion system also is needed. In the late 80's or early 90's, we develop a large chemical upper stage, capable of transporting man to the geosynchronous orbit but not initially used in that mode. The big investment, however, is a new heavy lift launch vehicle (in the size range needed by the SPS) and its corresponding launch facilities. Beyond the 90's this becomes fully operational and additional transportation hardware is needed to ferry cargo from the moon to the geosynchronous altitude.

The mainstream of benefits in the 80's is the services area: both information and observation. The world clearly benefits in education, health, and conservation of resources, and productivity. Lunetta now serves many cities and is on call for special situations.

In the 90's, we move to operational status — a solution to the basic energy scarcity problem. Beyond the year 2000 we make energy from our space installations the major worldwide energy source. Throughout the entire program we continue to expand services, make new products, and move toward full understanding, prediction, and localized control of our weather and climate. Most importantly, people get increasingly involved with space, first by receiving directly benefits such as information and light, but later on by direct participation in the space activity itself — even to space travel. A government/ industry partnership-for-growth develops between developing and industrialized countries, between the scientific and the academic community and commercial interests, and between space and terrestrial activities.

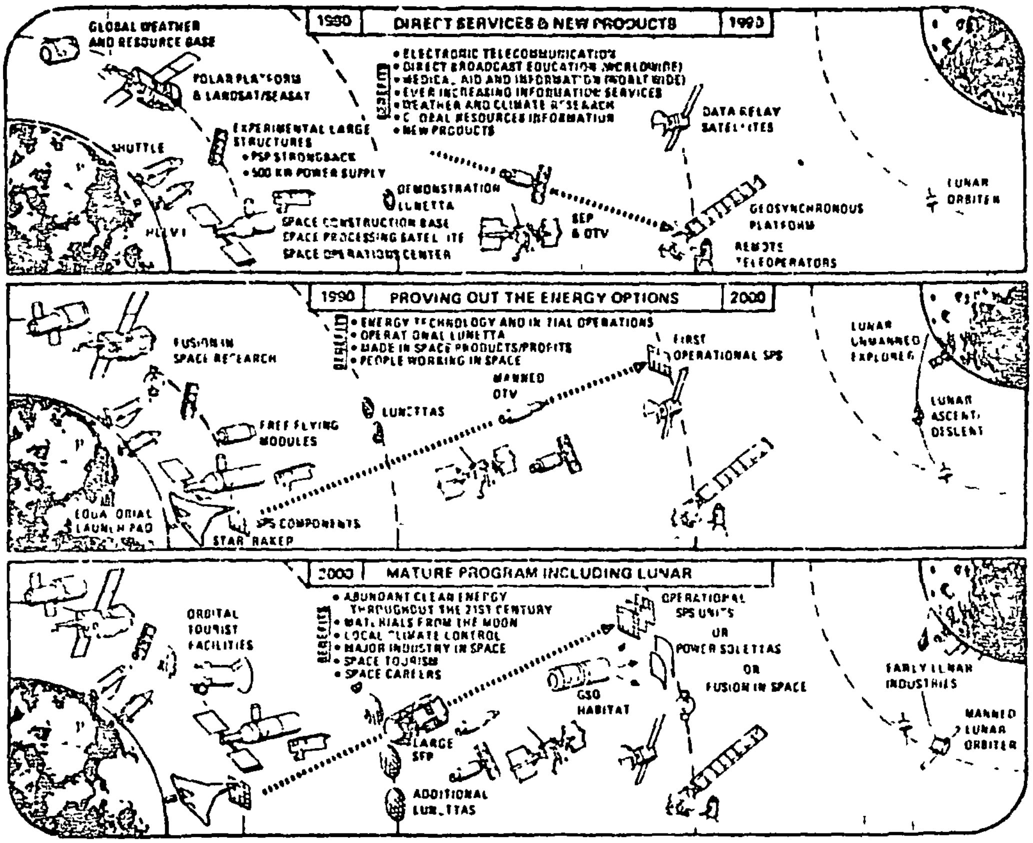

Figure 14. Space Industrialization Time Frame Summary Program Options

The hardware elements that are sketched in Figure 14 can be conveniently divided into six different categories:

1. Shuttle-Tended and Space Base Facilities
2. Space Processing Facilities
3. Geosynchronous Orbit Facilities
4. High Inclination Orbit Facilities

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5. SPS Development Hardware
6. Transportation Elements

These six categories of hardware and their associated operational procedures will be discussed in detail in the next six major subsections.

SHUTTLE-TENDED AND SPACE BASE FACILITIES

The first step in any major *space industrialization* effort must involve the intensive use of the Shuttle transportation system's unique operational capabilities. In particular, the Shuttle's ability to carry large two-way cargos into space will be necessary in developing economical space manufacturing and processing operations. In addition, its ability to refurbish and repair orbiting satellites will significantly enhance the reliability of many space activities that might otherwise be of, at best, only marginal. However, despite the importance of the Shuttle's operations to the *space industrialization* efforts, its role was not intensively assessed in the present study effort. This early part of the study was purposely held to a minimum because of limited funding levels and because many other studies have devoted much more abundant resources of time and money to studying the Shuttle's potential operations.

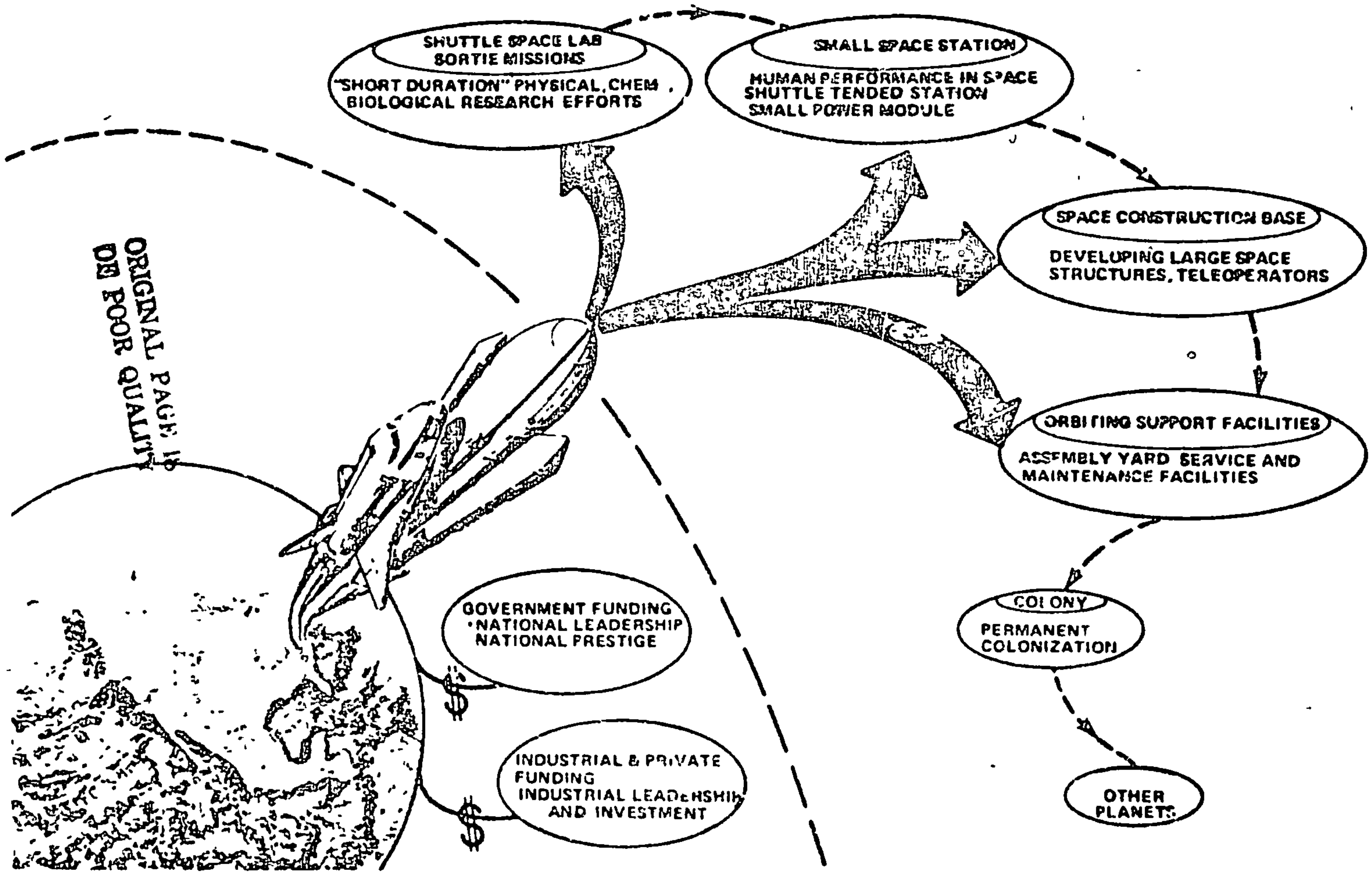
For example, the NASA/ASE Engineering Systems Design Summar Faculty Fellowship Program* which was recently conducted by the College of Engineering at the University of Alabama, investigated the promises of Shuttle-tended orbiting facilities in a highly detailed manner. It was the conclusion of this study team that a powerful program could be ushered in by the Shuttle/Skylab combination and that these relatively small beginnings could evolve into a far-reaching evolutionary program that would include a small space station, a space construction base, and orbiting support facilities. The sketch in Figure 15 was extracted from the final report published by this specialized study team. As can be seen, it previews an ambitious and forward-looking program that includes many early elements in common with the early *Space Industrialization* program.

Another detailed look at the possibilities that could emerge from early Shuttle-tended space facilities has been conducted by Rockwell International These advanced space station studies produced an evolutionary program which quickly expands from the early Shuttle sorties and Spacelab missions. The material to follow was extracted from the documents that were published as a result of this extended study.

Modular Facilities

Both MDAC and the Rockwell in-house *Space Station* studies concentrated on a modular approach whereby each module is Shuttle Orbiter compatible for launch and also for retrieval and return to earth if this becomes necessary. As far as the *Space Industrialization* study is concerned, these designs are considered representative and are as good a basis for overall costing as anything available.

*Planning for Materials Processing in Space, University of Alabama Summer Faculty Fellows in Engineering Systems Design, Grant No. NGT 01-002-095 (September 1977).



University of Alabama
1977 Summer Study

Figure 15. Structure Evolution

MDAC Modular Space Station

Both the MDAC and Rockwell studies began with a Shuttle-tended module in which the Orbiter provides all crew support and built from that to a continuously manned station. The following is taken from the MDAC report* and is a summary of their system.

For the Shuttle-tended SCB concept, the initial step in the buildup will consist of transporting the power module to orbit and deploying the solar arrays and radiator systems, then, the space construction module will be attached to the power module as shown in Figure 16. The power module will supply approximately 38 kW at the bus location. Also, the configuration is optimally oriented with regard to the sun-solar array aspects as well as minimum drag considerations. The orientation is adequate for both low-and high-beta angle situations. This concept is further illustrated in Figure 17, in which the Shuttle-tended mode is shown supporting construction of the antenna system.

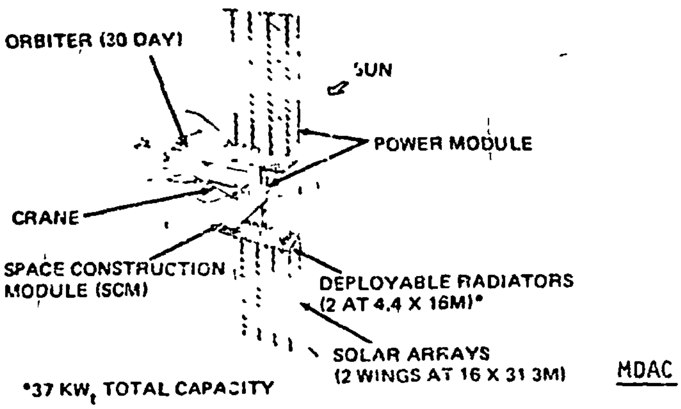


Figure 16. Shuttle-Tended SCB Concept

For the continuously manned mode of operations, a *construction shack* is delivered into orbit. With this addition of the *construction shack*, the space construction base would have the capability of being continuously manned. As shown in Figure 18, construction of the 30m torus radiometer could be undertaken and, with the construction of the 250 kW power platform the antenna could be completed followed by its testing and subsequent return to earth.

Spacelabs can be brought up and berthed to the *construction shack* at opportune times. Hence, the continuously manned construction base can replace the Orbiter as the support vehicle and, since orbital duration is unlimited, greatly increase the Spacelab mission capability. Thus, continued utilization of the existing Spacelab hardware and operational program structure is ensured.

The internal layout of the space construction module concept is illustrated in Figure 19. The module arrangement is dominated by the crane turret and berthing ports. Facilities for construction/test support while adequate are not extensive.

*Space Station Systems Analysis Study, Part 3: Documentation, Vol. 1 Executive Summary, McDonnell Douglas Astronautics Company MDC G6922 (July 1977).

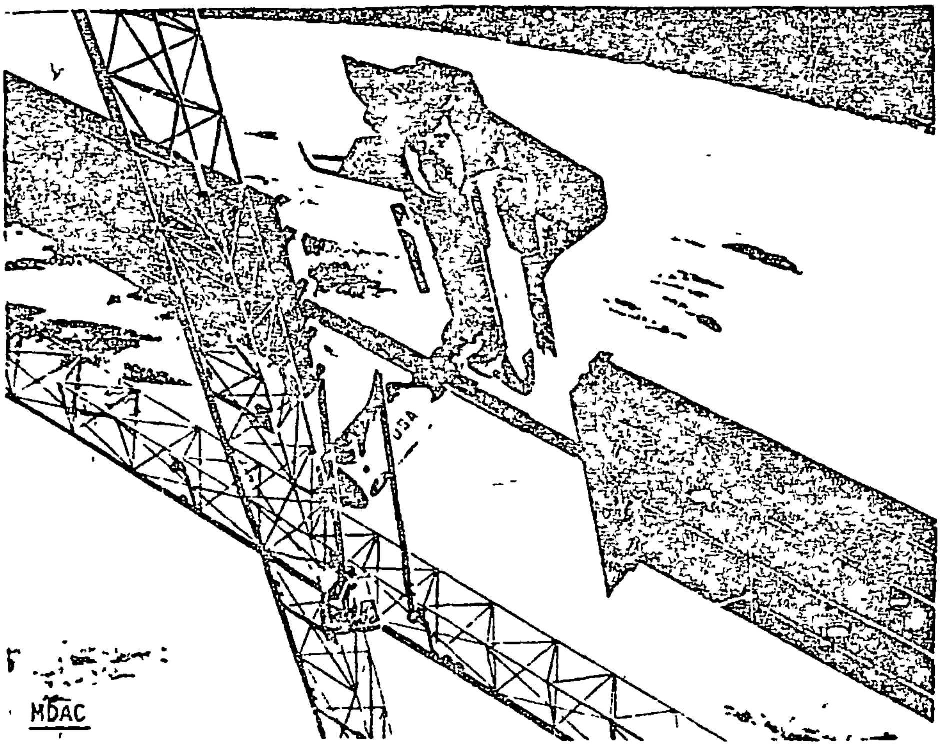


Figure 17. Assembly of Antenna System

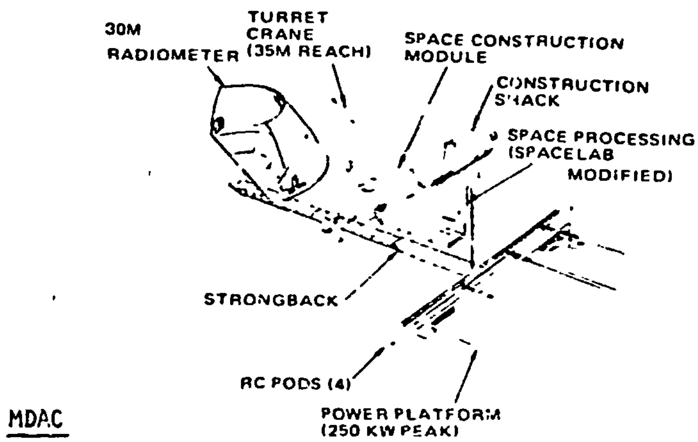


Figure 18. SCB - Construction Base Concept Continuously Manned

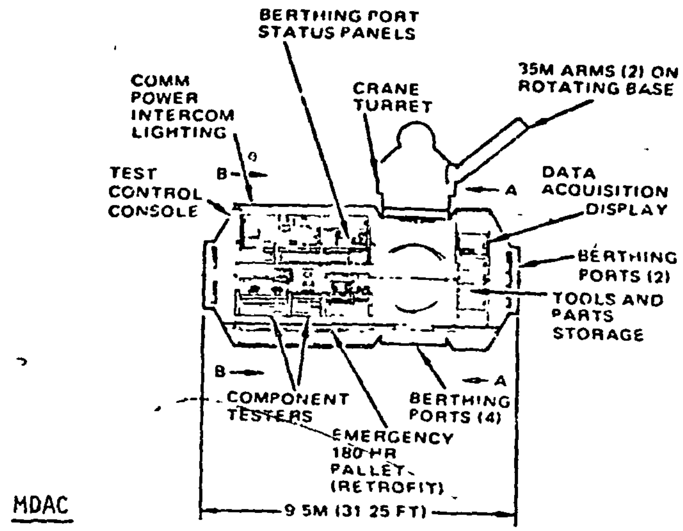


Figure 19. Space Construction Module Concept

Facilities for construction control and crew support systems (not shown) occupy the opposite side of the module. These include display and control modules, the microfilm retrieval unit, printer, schedule status panel and battery charging/gas replenishment equipment for the Orbiter suit maintenance and the life support systems. There is also a floodlight system which has been sized to illuminate a 1,000 m^2 surface area with an intensity of 216 lumens/m^2 during the approximately 36 minutes of darkness per orbit. These units will require 5 kW during operation. For completeness, the berthing/docking port lighting, work position lighting tracking lights, and safety lights have also been evaluated.

The module, as presented, is not a stand-alone concept. As described earlier, it requires either the Orbiter or the construction shack and either the power module or power platform to provide subsystems and resources for its operation. As such, it serves as an adjunct to the major SCB elements with the sole purpose of supporting construction. This approach results in a low-cost system while providing the necessary flexibility to support other program options.

Continuous manning will eventually be required to permit long periods of uninterrupted work, as in the space processing area, and to reduce the cost per manhour in orbit by reducing transportation costs through longer staytimes. This requires more habitability services for the crew than can be provided by the Orbiter alone.

The *construction shack* module (Figure 20) represents an austere low-cost approach for crew quarters and facilities without compromising crew safety or performance. As shown, the module contains a two-man Orbiter airlock with an EVA hatch, a control compartment, a wardroom and exercise area in the region of

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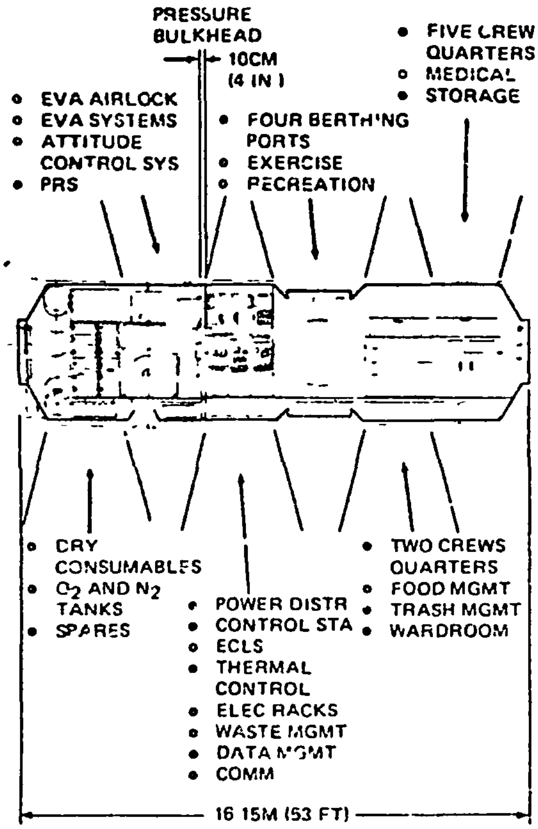


MDAC

Figure 20. Construction Shack Concept

the berthing ports, and crew sleeping quarters. Storage racks provide space for 60 to 90 days of consumables for a seven-man crew. The module has two pressurizable compartments separated by a common bulkhead.

Rockwell Modular Space Station

The following was taken from the Rockwell in-house *Space Station* study (Report SD77-AP-0127)

General Design Requirements

The Shuttle Orbiter is the transportation system utilized to place elements into low earth orbits. Consequently, all design concepts must be compatible with the Shuttle as to size, weight, c.g., location and orbit altitude. The maximum size of an element that can be carried as an Orbiter payload is illustrated in Figure 21. The size indicated (48 feet) assumes that the Orbiter is docked to an orbiting element or space station with a maximum diameter of 15 feet and that the element in the Orbiter payload bay must be extracted past this item. The extraction clearances considered adequate for this maneuver are also shown in the figure. The maximum length payload when the orbit requires an

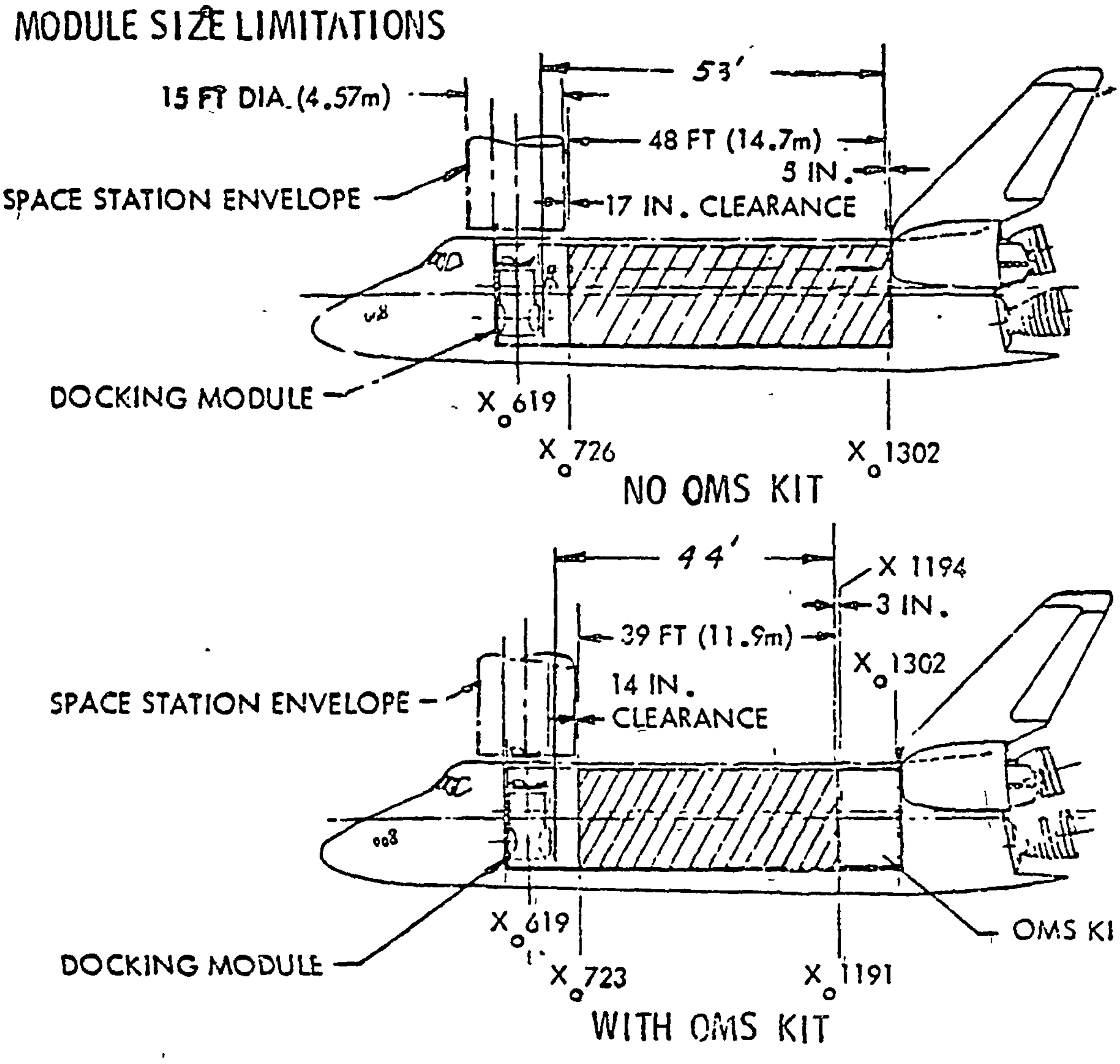


Figure 21. Shuttle Orbiter Physical Constraints

OMS kit for proper orbit insertion is shown to be 39 feet. An additional 5 feet can be added to the length of the module when no rendezvous maneuver docking to another orbiting element is required. The maximum module length, therefore, can be 53 feet with no OMS kit or 44 feet with an OMS kit.

Figures 22 and 23 show the parametric charts that were developed to determine the maximum payload that can be placed in orbit and observe the acceptable c.g. location. The payload density was also verified. The maximum density of 10 lb/ft^3 was considered to be the upper limit so that all payloads should be less than that number. Since most of the orbit operations are planned for the 250 N. mile range of altitudes, the principle concern was to generate data at this range of altitudes. Table 1 summarizes the data obtained from the charts. A uniform weight distribution was assumed for the modules, therefore, the c.g. location of the module was in the center of the module. These charts provided a first cut approximation when determining the feasibility of launch to altitude of element concepts.

Extended Duration Orbiter (EDO)

The early periods of *space industrialization* use extended duration Orbiters for missions up to 90 days duration, with crew compliments up to seven crewmen. Certain modifications are required in order to accommodate the crew, provide electrical power and accept operations for these periods. The following text will describe the effort accomplished in a separate IR&D study for defining the Orbiter requirements for extended duration missions. The items that were investigated were those of habitability, consummables storage volume and water requirements, electrical power requirements, and EVA influence.

<u>Habitability</u>. The Orbiter crew cabin is designed to accommodate four crewmen and has dedicated storage volume for 42-man days. Consequently, when mission durations exceed the baseline capability, additional provisions must be made. Accommodation of the crew involves the free volume per man, consumables storage and water quantities for drinking and washing.

Free Volume. What is the acceptable free volume per man for missions up to 90 days? Previous studies by NASA[1,2] have addressed the question and the results applicable to the extended duration Orbiter operations are shown in Figure 24. This figure indicates that the available volume per man for a seven-man crew — 120 ft^3/man becomes unacceptable for mission durations longer than 15 to 20 days. No constraint on a four-man crew is indicated. The free volume of 120 ft^3/man includes both the upper and mid-deck volumes of the Orbiter. The activities that were evaluated to derive the curves of Figure 24 are listed in the upper right corner of the figure and represent all of the known activities that would be performed during a typical mission. However, the activity of concern for the EDO are those items associated with personal activities and sleep and privacy. These activities are assigned to the mid-deck area of the baseline Orbiter. Therefore, the volume of this area of activity

[1] Freser, T. M., <u>The Effects of Confinement as a Factor in Manned Space Flight</u>. NASA-CR-511 (1966).

[2] Fraser, T. M., <u>The Intangibles of Habitability During Long Duration Space Missions</u>. NASA-CR-1084 (1968).

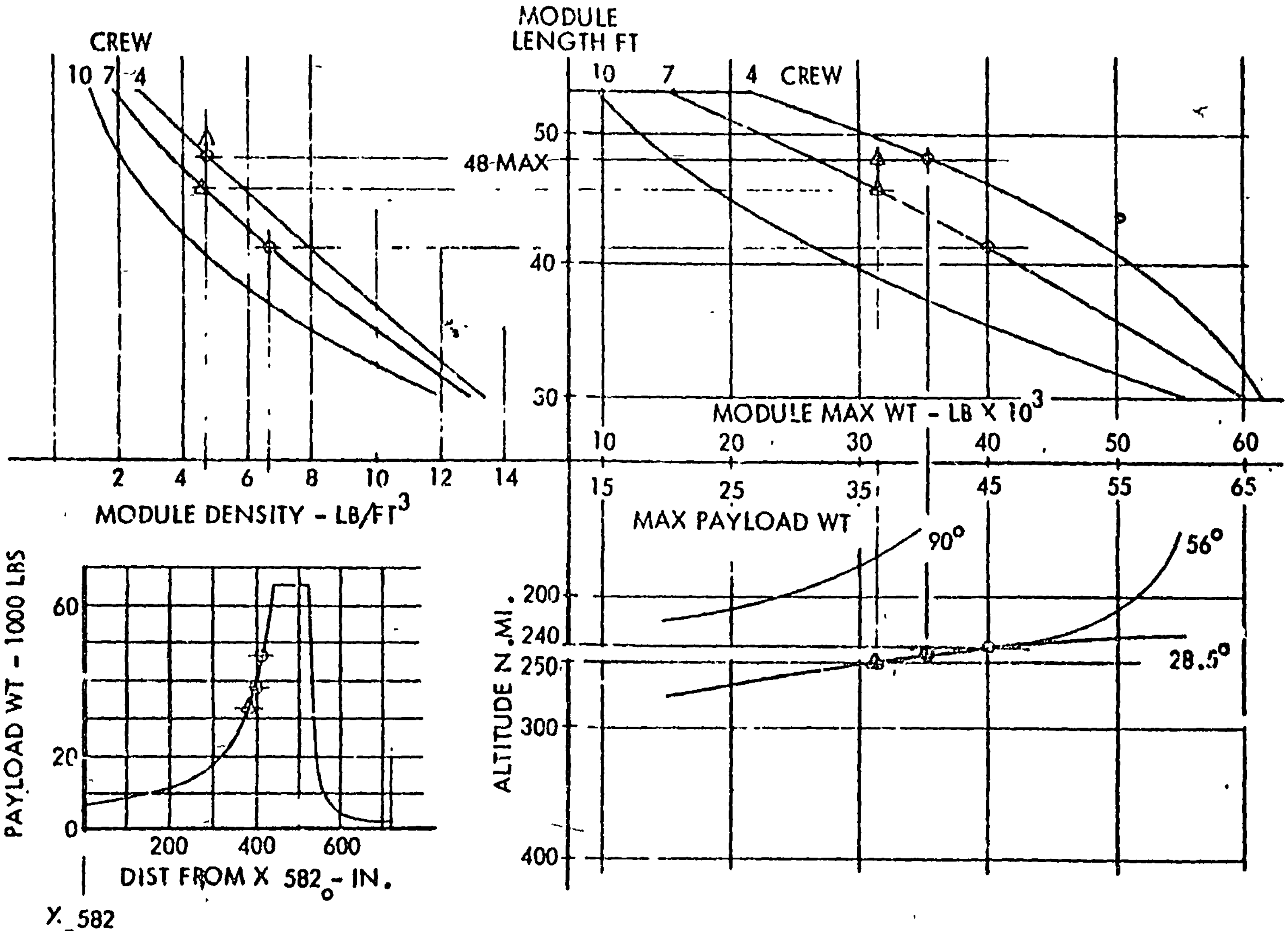


Figure 22. Shuttle Orbiter Weight and Balance Constraints No OMS Kit

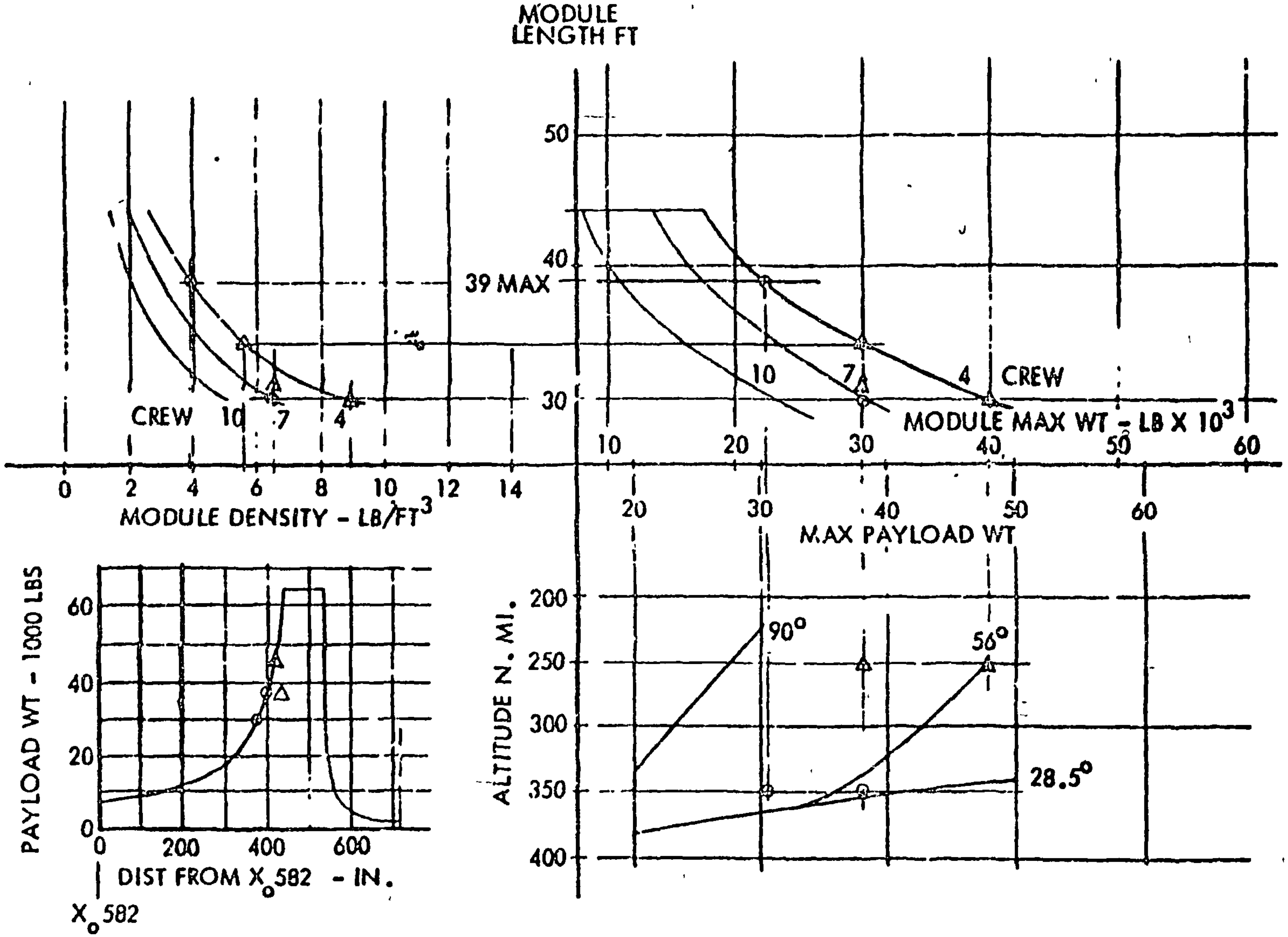


Figure 23. Shuttle Orbiter Weight and Balance Constraints with OMS Kit

Rockwell International
Space Division

Table 1. Module Sizing Summary

	ALTITUDE NMI	INCLINATION	MODULE WEIGHT**	PAYLOAD WEIGHT*	MOD LGH (FT)	DENSITY (LB/FT^3)	ORBITER CREW/PASS.	TYPE MODULE
NO OMS KIT	240	28.5°	36,000	39,600	48	.5	4	SM, CORE POWER
		56.0°	40,000	44,600	41	6.6	7	RESUPPLY
	250	28.5°	32,000	35,600	48	4.2	4	SM, CORE POWER
		56.0°		36,600	46	4.4	7	RESUPPLY
WITH OMS KIT	250	28.5°	30,000	37,000	34	5.8	4	SM, CORE POWER
		56.0°	30,000	38,000	30	6.4	7	RESUPPLY
	350	28.5° 56.0°	22,000	29,000	39	3.8	4	SM, CORE POWER
		28.5°	30,000	30,000	30	6.4	7	RESUPPLY

* PAYLOAD WT INCLUDES DOCKING MODULE/PROVISIONS OMS KIT/ PROVISIONS PASSENGERS (MORE THAN 4 CREW) 2ND "K" BAND ANTENNA

** MODULE WT INCLUDES 25% GROWTH ALLOWANCE

CONCLUSION:

FOR ORBIT ALTITUDES BETWEEN 240/250 NMI UTILIZE;

- 48 FT MODULES
- 32,000 LB MAX WT
- NO OMS KIT

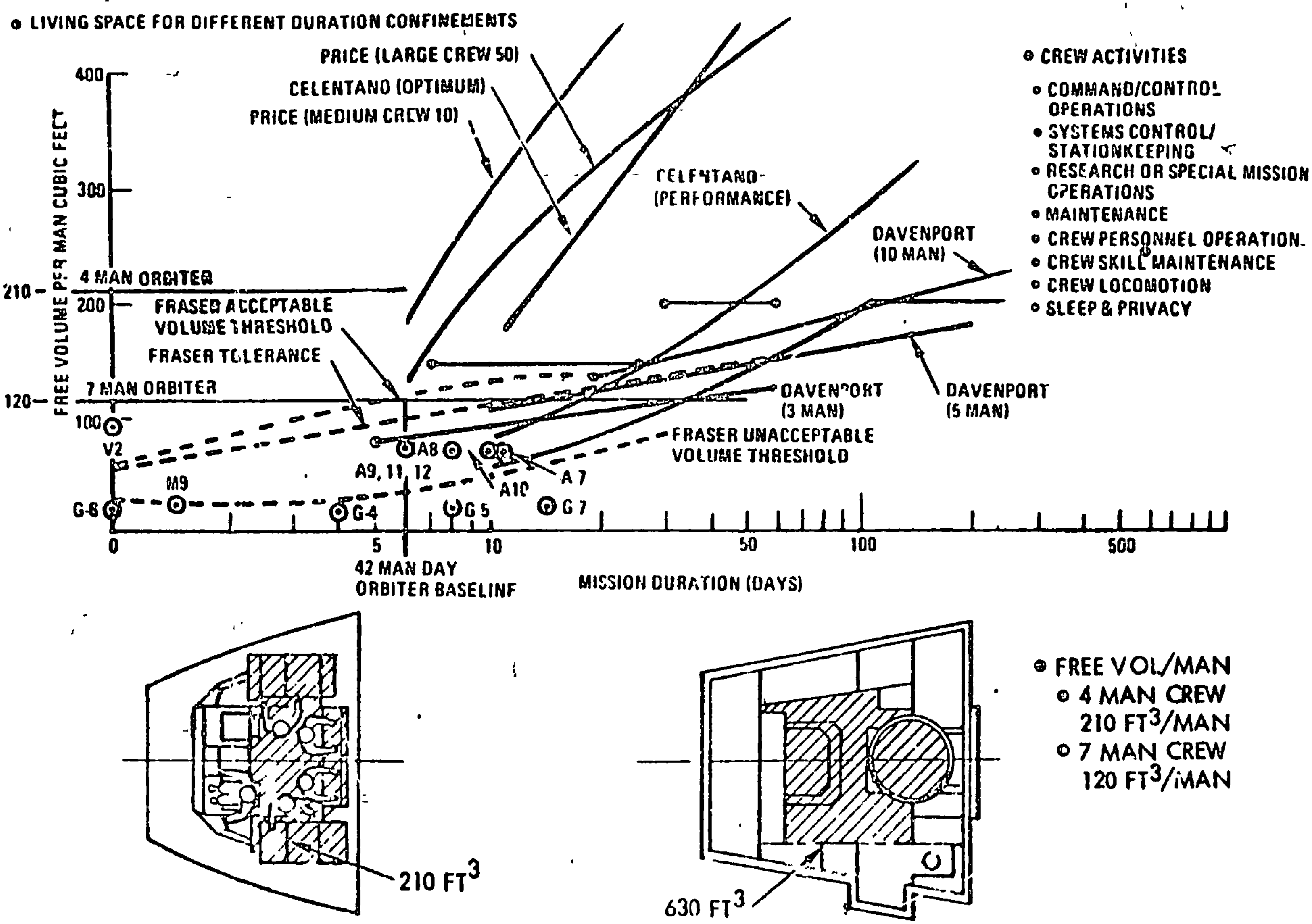


Figure 24. Free Volume

only will be used in determining an acceptable volume per man for the personal activities and sleep and privacy functions. Figure 25 indicates the volume/man available for two arrangements of the mid-deck. The baseline four crewman Orbiter provides 95 ft^3/man for the activities in question with only 67 ft^3/man for a crew of seven with the airlock in. A volume per man of 84 ft^3 is available when the airlock has been removed from the mid-deck and placed into the payload bay. The 84 ft^3/man is considered to be marginally acceptable. However, sleep provisions are available per the baseline for only four crewmen. Additional facilities must be provided when more than four crewmen are on board. For this discussion, we are assuming that each crewman will have his own sleep and privacy provisions rather than share provisions. For missions of 15 to 20 days, sleep arrangements as shown in Figure 26 may be acceptable. However, for missions greater than 15 to 20 days, sleep arrangements in a separate pressurizable module placed in the payload bay is recommended. The mid-deck area of the Orbiter would be arranged as shown in Figure 27. This arrangement provides a volume per man figure essentially equivalent to that provided by the baseline Orbiter for the four crewman — 65 ft^3/man for four crewman, baseline arrangement, versus 70 ft^3/man for the seven crewman arrangement. The sleep and privacy accommodations of 30 ft^3/man provided in the baseline Orbiter will be maintained for all mission durations. Consequently, a nominal figure of 100 ft^3/man for personal activities and sleep and privacy functions is recommended for all missions.

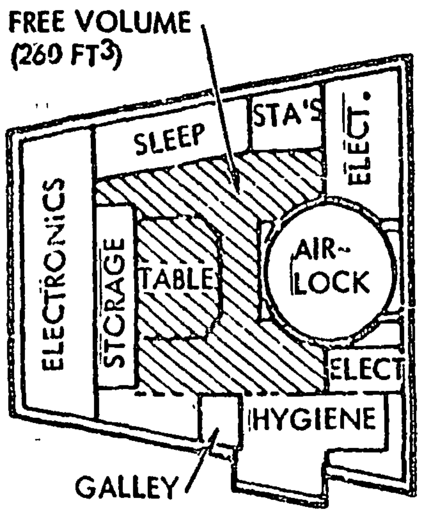
Consumable Storage Volume. The baseline Orbiter has dedicated storage volume for 42-man days supplies. Additional volume must be provided for consumables storage when mission durations exceed the baseline. The amount of volume required for the various items included in a supplies manifest is shown in Figure 28. The manifest includes the contingency supplies as well as the normal operations supplies. The manifest is also separated into fixed items that are purely crew dependent and those that are crew/time dependent. Figure 29 is a parametric chart developed from the manifest with weight and volume versus mission duration relationships indicated. The basic Orbiter utilizes $LiOH$ as the CO_2 removal agent. However, because of the large volume required for storage of the $LiOH$ canisters, the introduction of a CO_2 regenerative concept such as a solid amine or MOL Sieve concept for long-duration missions become effective and this influence, therefore, is also represented on the parametric chart.

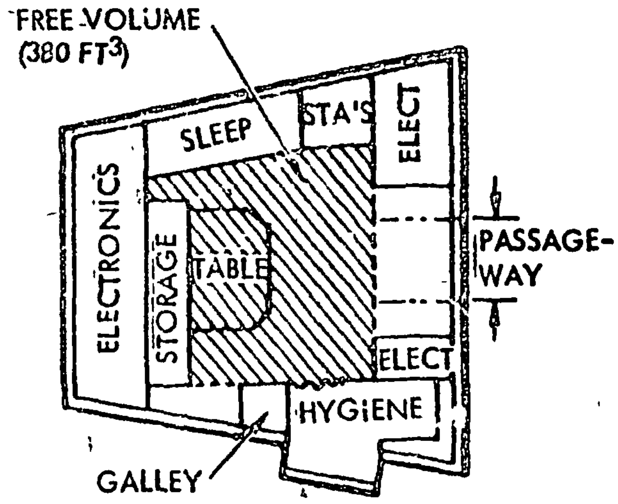
An unallocated volume of 73 ft^3 exists in the baseline Orbiter stowage volume. In determining the amount of pressurized stowage volume required for extended duration missions, this unallocated volume is used as consumable storage volume. Figure 30 indicates the volume required over and above the 42-man day baseline Orbiter allocated volume required for consumables storage.

Because both the sleep and privacy volume and the consumables storage volume are required to be in a pressurized mode, these two requirements can be integrated. The concept of utilizing a short spacelab structure for this function was investigated. It was determined that the spacelab module in conjunction with the 73 ft^3 of unallocated orbiter stowage volume is sufficient to accommodate a 90 day mission duration with seven crewmen. A sketch of this arrangement is illustrated in Figure 31. Sufficient volume is

VOLUME AVAILABLE FOR PERSONAL OPERATIONS

- BASELINE ORBITER
  - WITH AIRLOCK
    - 30 FT³/MAN - SLEEP/PRIVACY QUARTERS
    - 65 FT³/MAN - 4 MAN
    - 37 FT³/MAN - 7 MAN
  - WITH-OUT AIRLOCK
    - 30 FT³/MAN - SLEEP/PRIVACY QUARTERS
    - 95 FT³/MAN - 4 MAN
    - 54 FT³/MAN - 7 MAN





- 4 MAN-ACCEPTABLE FOR ALL MISSION
- 7 MAN
  - SHARED BUNKS
  - UNACCEPTABLE FOR > 10 - 15 DAY MISSIONS

- 4 MAN-ACCEPTABLE FOR ALL MISSIONS
- 7 MAN
  - ACCEPTABLE VOLUME
  - SHARED BUNKS - UNACCEPTABLE FOR >10 - 15 DAY MISSIONS

Figure 25. Orbiter Free Volume

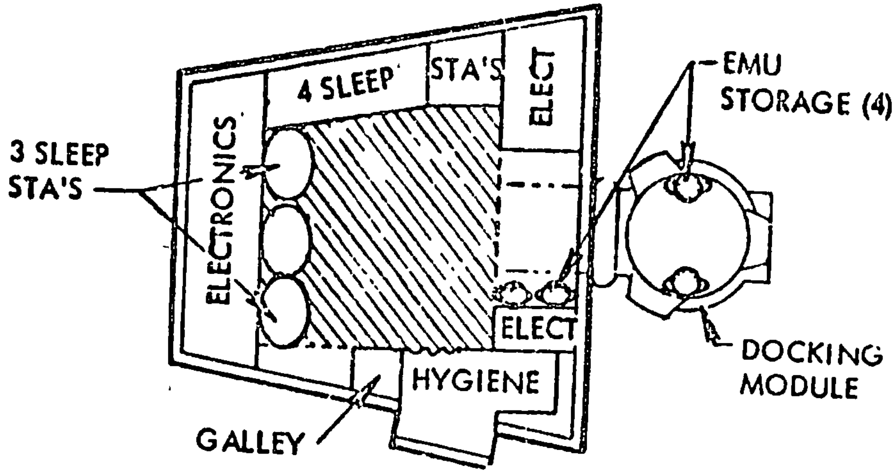
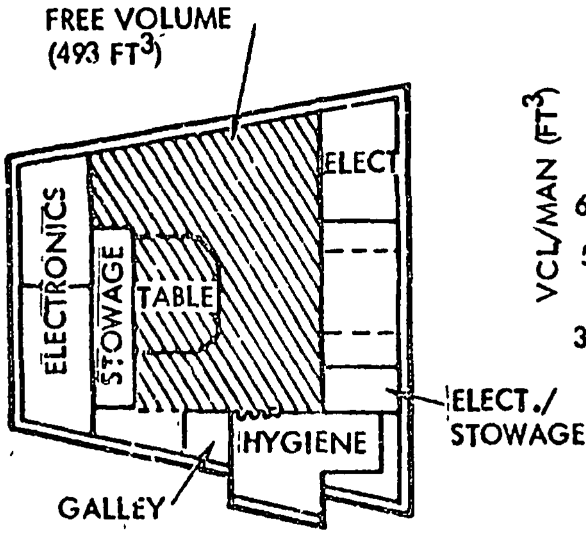
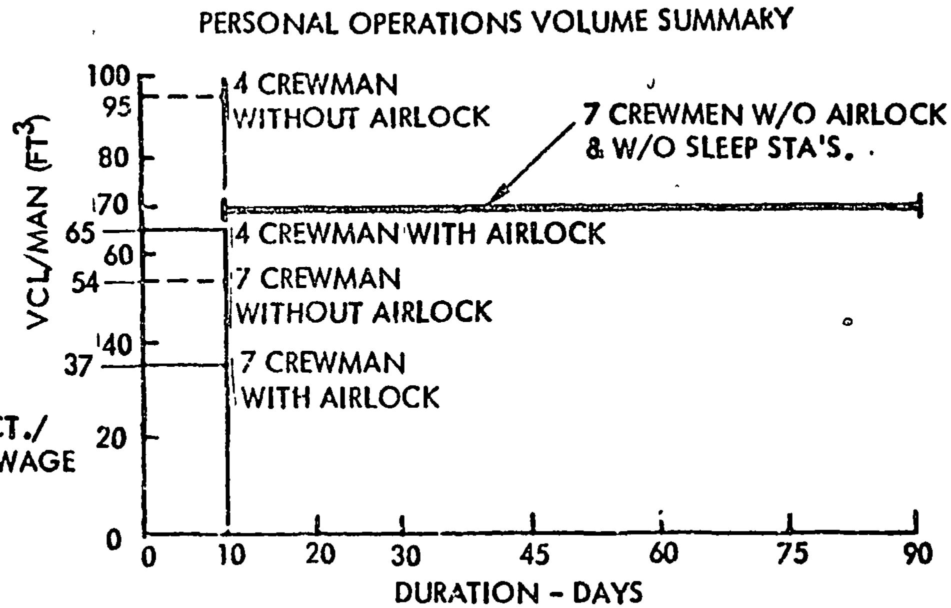


Figure 26. Limited Duration Cabin Arrangement

RECONFIGURED CREW MODULE FOR MISSIONS > 10-15 DAY DURATION





CONCLUSIONS:

- PERSONAL ACTIVITIES VOLUME OF ≈ 100 FT^3/MAN (70 FT^3-PERSONAL OPERATIONS, 30 FT^3 SLEEP & PRIVACY) SHALL BE PROVIDED FOR ALL MISSIONS.
- NO SHARING OF SLEEP/PRIVACY QUARTERS FOR MISSIONS GREATER THAN 10-15 DAYS.

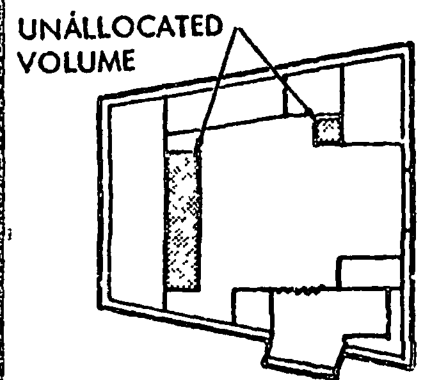
Figure 27. Orbiter Free Volume

SUPPLIES MANIFEST

ITEM	FIXED ITEMS (CREW DEPENDANT) WT MAN (LBS)(2)	DENSITY (NO FT^3)	VOL MAN (FT^3) ALLOCATED	REQ'D	VARIABLE ITEMS (CREW MISSION DEPENDANT) WT (NO/MD)(2)	DENSITY (NO/FT^3)	VOL MD (FT^3)	FIXED ITEM (SLEEPING BAG CONCEPT) VOL/MAN FT^3
CREWMAN	170							
SEATS	54		X					
RESTRAINTS	5	7.0		71				
SLEEPING BAG	3.5	10.0	(1) X					35
TRASH CONTAINERS					1	10	10	
FOOD'								
CONTINGENCY	13.3	20.0		67				
CONSUMMABLE					5.53	20	26	
CREW PROVISIONS								
WEAR ON	10.8	10.0	(1) X		2.4	10	24	1.65
STOWABLE	16.5							
HYGIENE	6.9	10.0		69	1.8	10	18	
EMERGENCE/ RESCUE	58.8	40.0		1.50				
RACKS					14.30			
TOTAL	338.8			3.57	14.30		80	2.0
FOOD								
CONTINGENCY	21.6	23		94				
CONSUMMABLE					5.39	23	23	
TOTAL	360.4			4.51	19.59		1.03	

(1) VOL INCLUDED IN SLEEP PRIVACY QUARTERS

(2) WTS INCLUDED 5% GROWTH



- 42 MANDAYS STORAGE BASELINE
- 73 FT^3 UNALLOCATED STORAGE VOL.

Figure 28. Extended Duration Orbiter Supplies

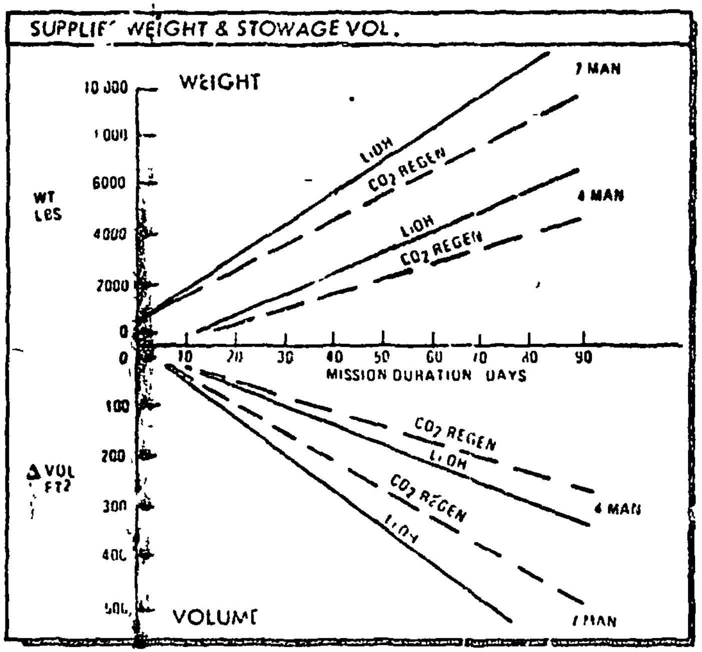
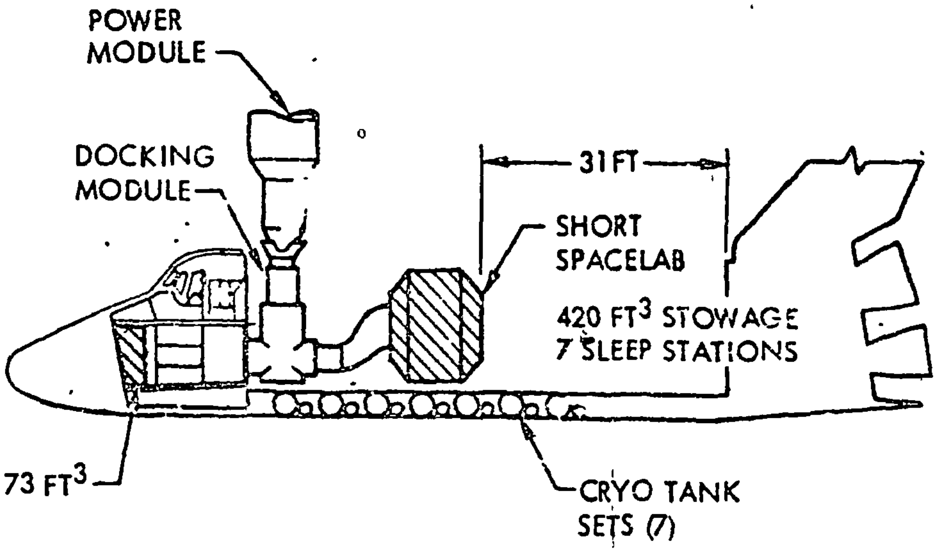


Figure 29. Supplies Weight & Stowage Volume



7 CREW CONFIGURATION

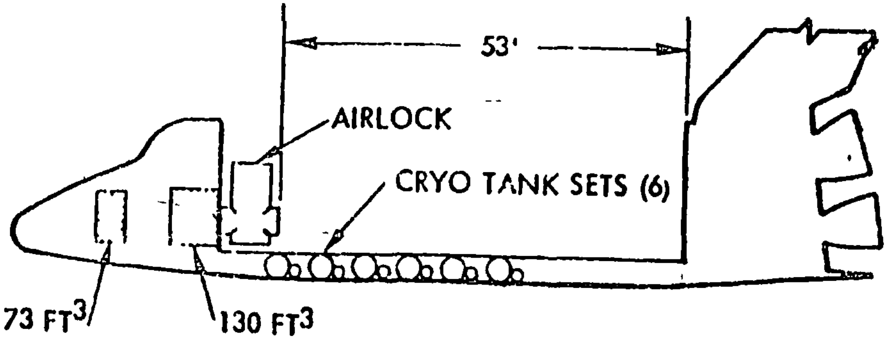
CONFIG CHARACTERISTICS

- EPS
  - SOLAR ARRAY/FUEL CELLS
  - CRYO TANK SETS (7) (UPDATED TANKS)
- ** CONSUMMABLES
  - VOL REQ'D - 495 FT^3
  - VOL AVAIL - 493 FT^3
- PAYLOAD AVAILABLE
  - VOL - 5478 FT^3
  - LENGTH - 31 FT
  - *WT 10,860 LBS

(NOTE: SUBSYSTEM COMPONENTS UPGRADED FOR MISSION LIFE TIME)
*28 1/2 INCL 250 NMI ORBIT (36,000 LBS)
**REGEN. CO_2 CONTROL

Figure 30. Electrical Power Augmented Orbiter - 90 Day Mission

- CONFIG CHARACTERISTICS
  - EPS
    - FUEL CELLS
    - CRYO TANK SETS - 6
  - CONSUMMABLES
    - VOL REQD - 98 FT^3
    - VOL AVAILABLE - 203 FT^3
  - PAYLOAD AVAILABLE
    - VOL - 8550 FT^3
    - LENGTH - 53'
    - * WT 29,911 LB
- 28 1/2° INCL 250 N.MI. ORBIT (36,000 LBS)



7 CREW CONFIGURATION

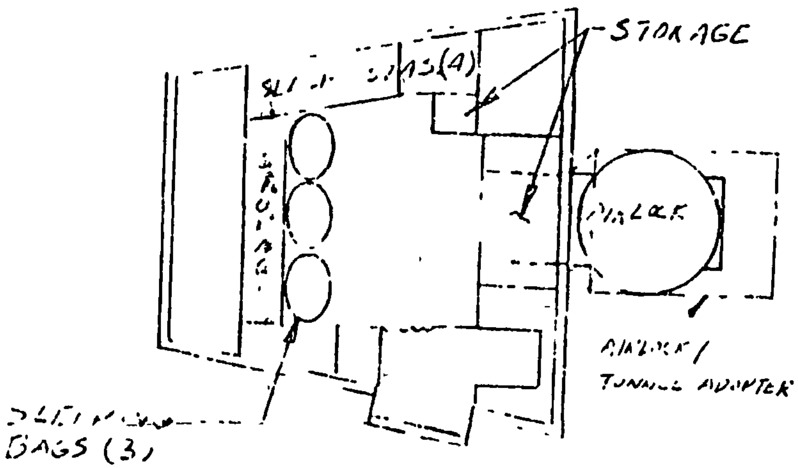


Figure 31. Baseline Orbiter - 15 Day Mission

available in the orbiter crew cabin to accommodate a 15 day mission with seven crew man. The orbiter arrangement for this mission also is shown in Figure 31. For mission durations between 15 days and 90 days, seven sleep and privacy quarters can be provided in a separate module such as the Spacelab concept. The module can also be used to store the consumables with its full capacity not being utilized until the 90 day seven man mission.

Crew Water Quantities. The crew ~~drinking~~ and wash water is provided by ~~the fuel cells.~~ The quantities of water required are shown in Figures 32 and 33 in relationship to the fuel cell operation. Figure 32 shows that sufficient water is generated during normal baseline fuel-cell operations to accommodate four men for approximately 60 days. However, if a seven-man crew is present then it will require additional cryo tank sets for missions greater than 30 days. Figure 33 indicates that the fuel cells need not be generating more than 2 kW to 3 kW of power to supply the total crews drinking and wash water requirement. This data does imply that regardless of the operational procedure of an EDO, i.e., utilizing supplementary power via a power module, the fuel cells in the Orbiter must continue to be operated at the 2 kW to 3 kW level in order to provide the water even when it is not required for electrical power.

Electrical Power. Figure 34 illustrates the Shuttle Orbiter electrical power capability. Seven cryo kits can be installed under the payload bay lines, thus permitting total volume utilization of the payload bay. This arrangement will also provide 7 KW continuous power to the payload up to approximately 11 days. Missions requiring larger durations also require additional cryo kits. These additional kits will be placed in the payload volume thus reducing that available for payloads. The reduction in available payload weight as a function of mission durations and cryo kits required is shown in Figure 35. The observation to be drawn from these two charts is that for mission durations greater than 11 days, augmented power in the form of an orbiting power module would be desirable. This arrangement would permit total utilization of the payload bay. Figures 36 and 37 show configuration concepts for a 30 day and 60 day orbiter utilizing the augmented power.

Extra Vehicular Activities (EVA). A very general analysis was performed to determine the affect on the Orbiter stowage volume if the number of EVA's exceeds the Orbiters baseline facilities. The influence of more than two crewmen performing EVA was also investigated. Figure 38 illustrates the various Orbiter configurations from which EVA could be performed. The figure also indicates the amount of consumables required for each airlock pressurization, and the volume required for each additional extravehicular mobility unit (EMU). Forty-five pounds of consumables is required for each additional airlock pressurization which occupies 2.5 ft^3. This volume is not required to be in a pressurized environment since it represents tankage volume. However, the 11 ft^3 required for each EMU is pressurized volume, and must be accounted for along with the additional volume required for extended duration missions habitability considerations.

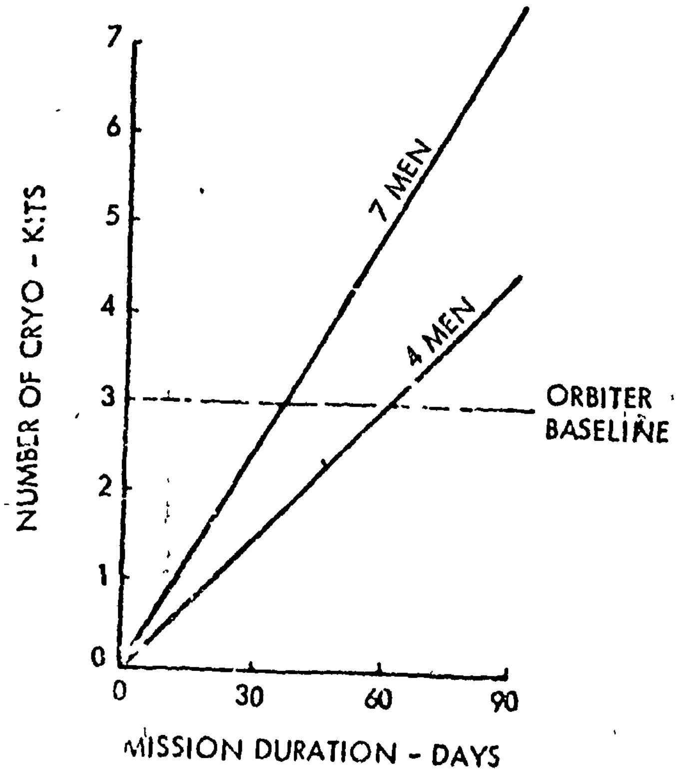


Figure 32. Crew Drinking and Wash Water Requirements

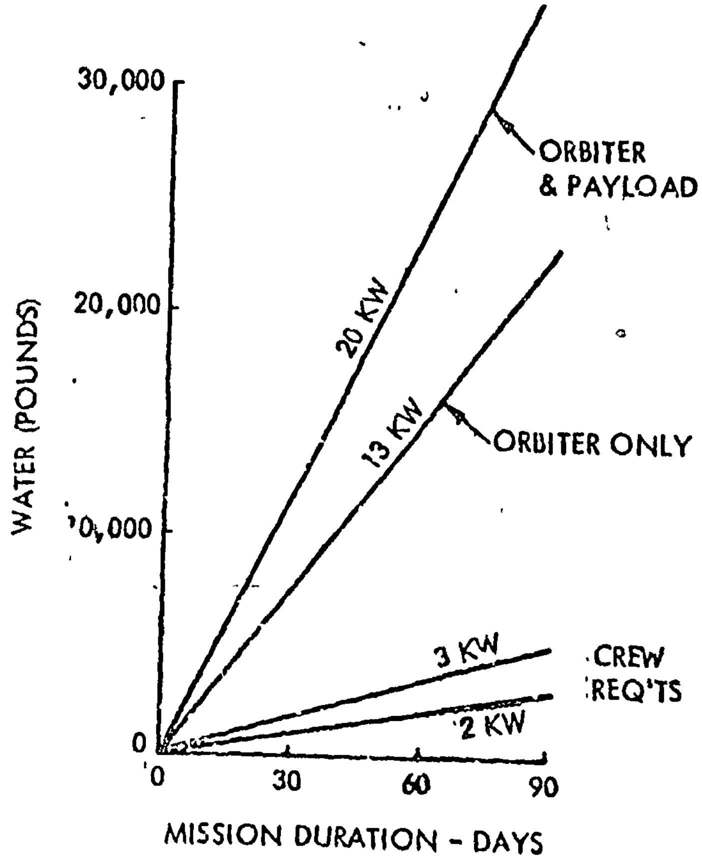


Figure 33. Fuel Cell Water Production

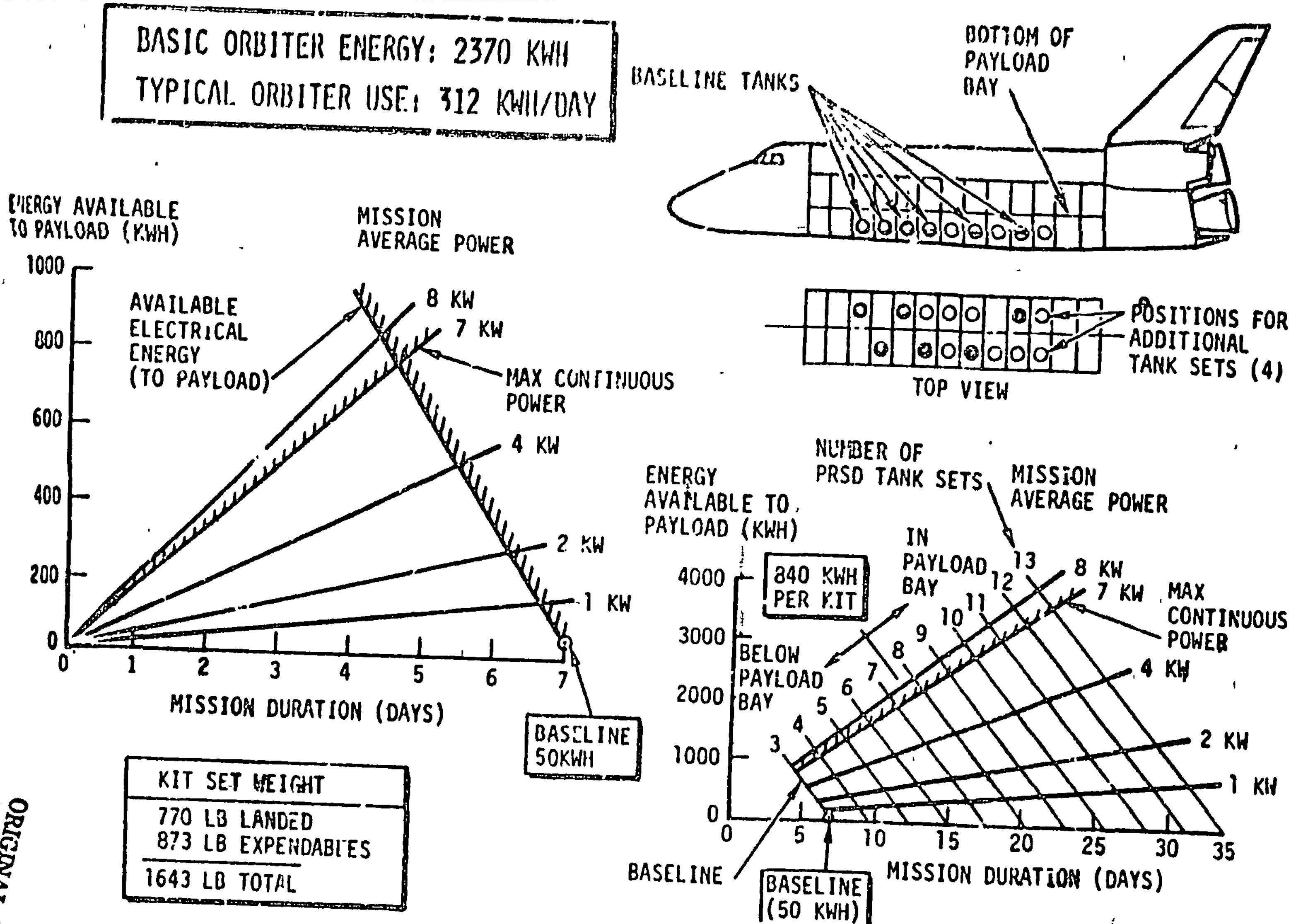


Figure 34. Energy/Power Available to Payload

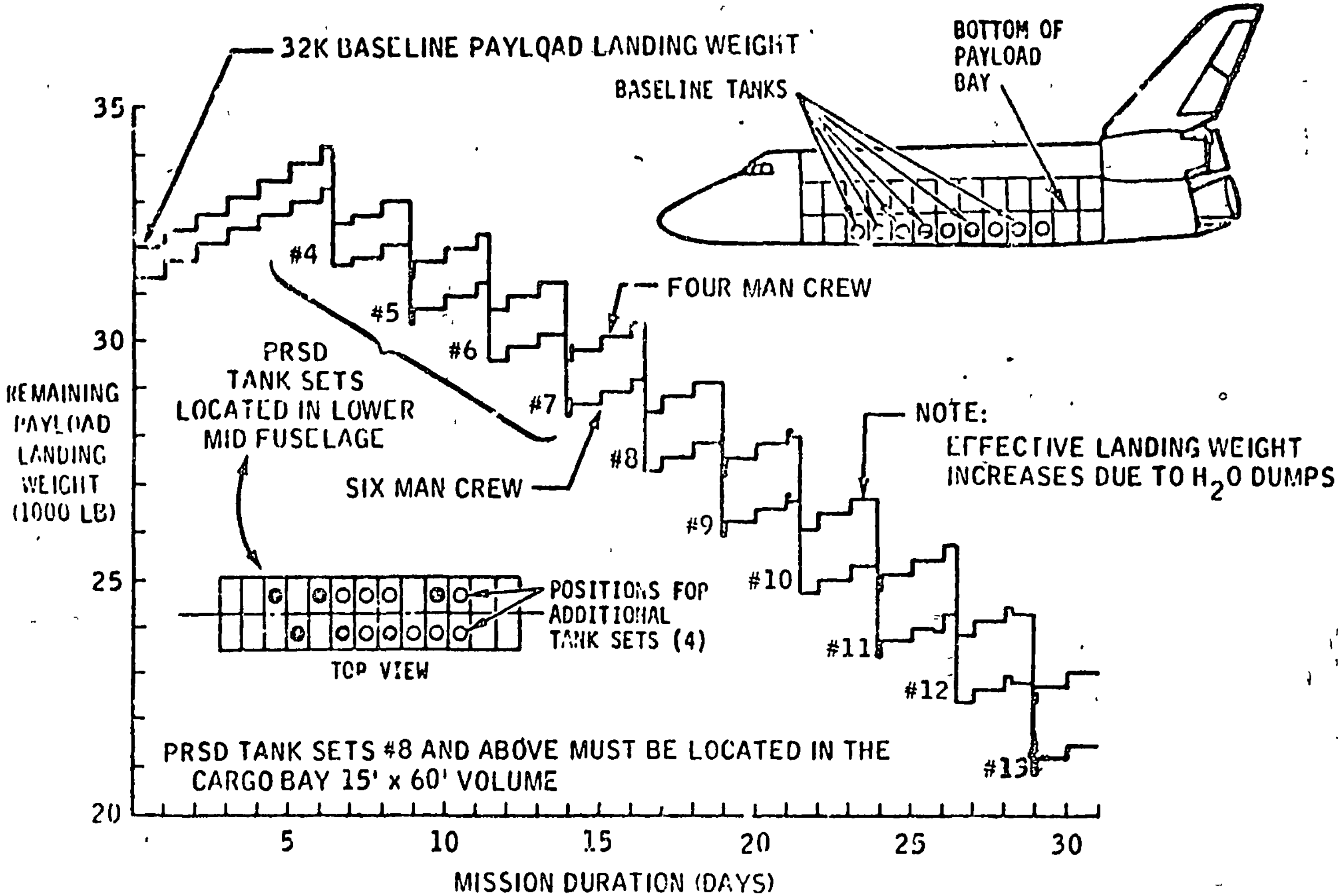


Figure 35. Reduction in Payload Landing Weight for Extended Mission Durations

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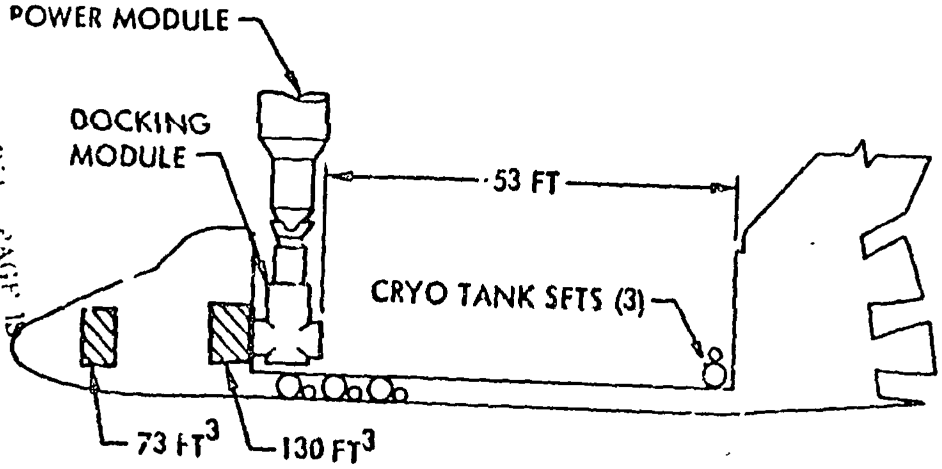
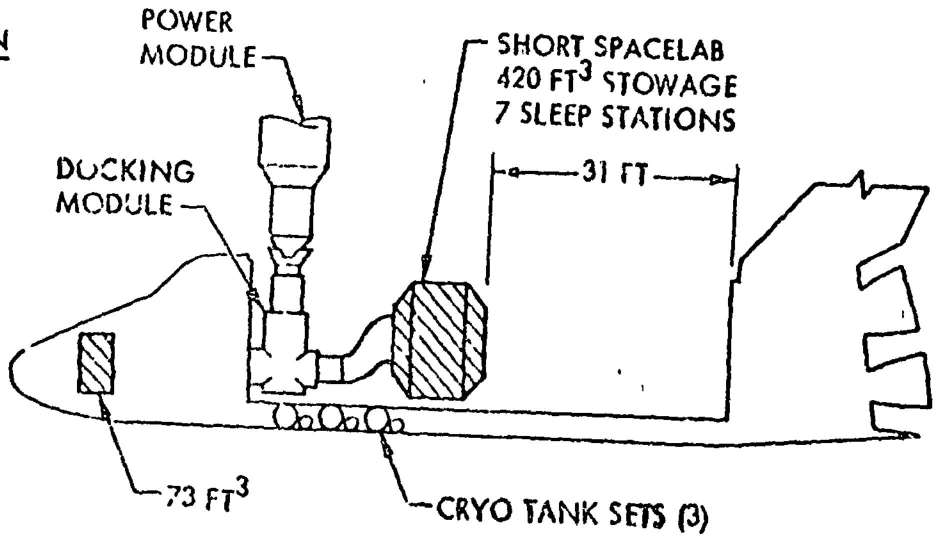
Space Division



4 CREW CONFIGURATION

- CONFIG CHARACTERISTICS
  - EPS
    - SOLAR ARRAY/FUEL CELLS
    - CRYO TANK SETS - 3
  - CONSUMMABLES
    - VOL REQD --98 FT^3
    - VOL AVAILABLE - 203 FT^3
  - PAYLOAD AVAILABLE
    - VOL - 8835 FT^3
    - LENGTH - 53 FT
    - WT 31,520 LB

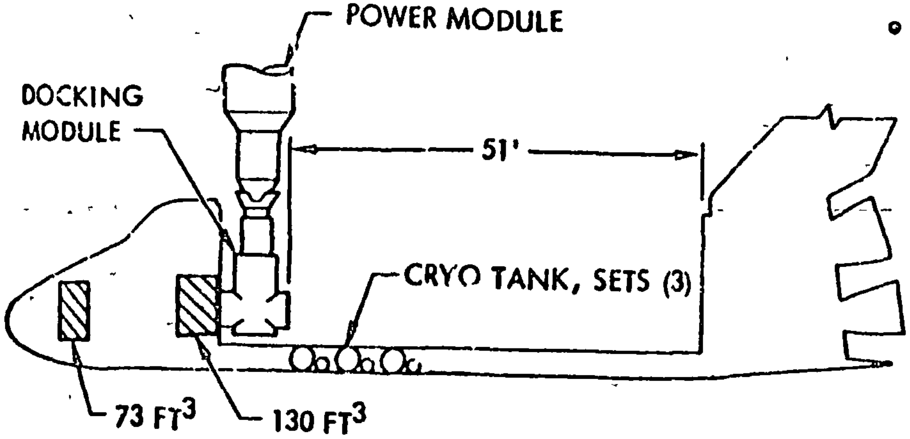


7 CREW CONFIGURATION

- CONFIG CHARACTERISTICS
  - EPS
    - SOLAR ARRAY/FUEL CELLS
    - CRYO TANK SETS - 3
  - CONSUMMABLES
    - VOL REQD - 205 FT^3
    - VOL AVAIL - 493 FT^3
  - PAYLOAD AVAILABLE
    - VOL - 4950 FT^3
    - LENGTH - 31 FT
    - *WT 25,967 LB

*28 1/2° INCL, 250 NMI ORBIT (36,000 LBS)

Figure 36. Electrical Power Augmented Orbiter - 30 Day Mission



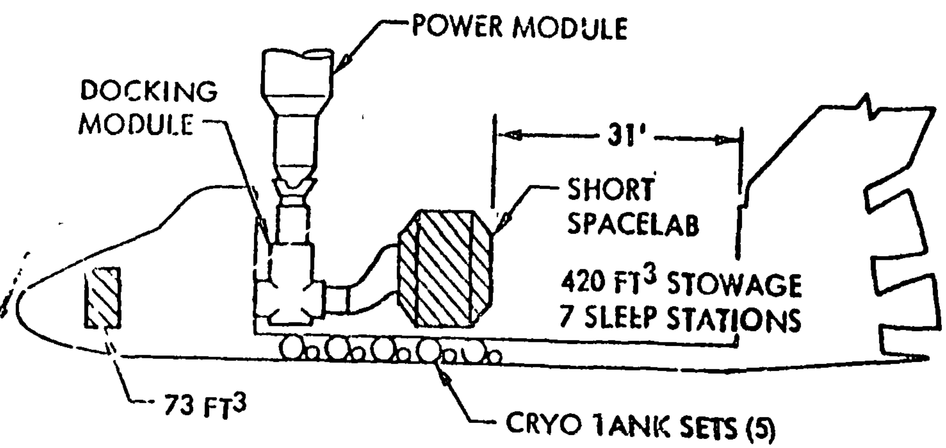
- CONFIG CHARACTERISTICS
  - EPS
    SOLAR ARRAY/FUEL CELLS
    CRYO TANK SETS -3
  - ** CONSUMMABLES
    VOL REQD -173
    VOL AVAILABLE -203
  - PAYLOAD AVAILABLE

    VOL 9012 FT^3
    LENGTH 51'
    *WT 25,970 LB

4 CREW CONFIGURATION

- CONFIG CHARACTERISTICS
  - EPS
    SOLAR ARRAY/FUEL CELLS
    CRYO TANK SETS-5
  - ** CONSUMMABLES
    VOL REQD -327 FT^3
    VOL AVAIL -493 FT^3
  - PAYLOAD AVAILABILE

    VOL 5480 FT^3
    LENGTH 31'
    *WT 20,720 LB



7 CREW CONFIGURATION

*28 1/2° INCL 250 N.MI. ORBIT (65,000 LBS)
**REGEN CO_2 CONTROL

Figure 37. Electrical Power Augmented Orbiter - 60 Day Mission

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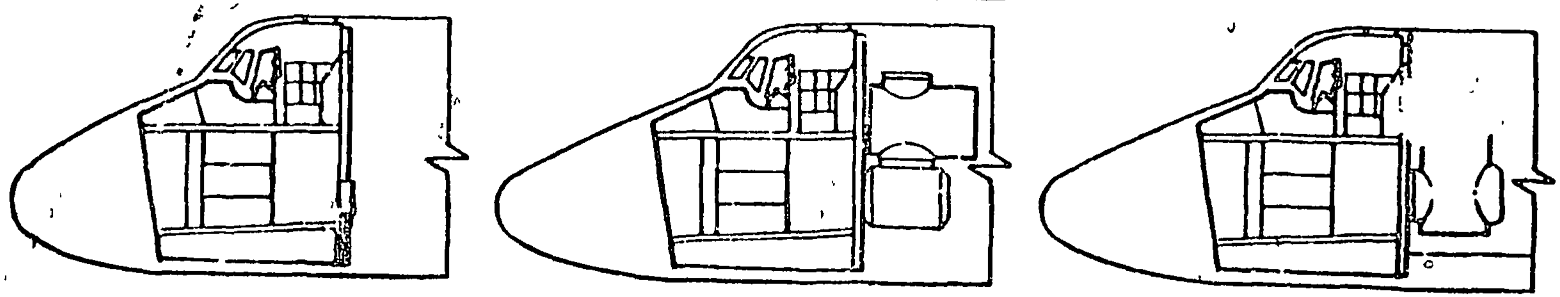
Space Division

- BASELINE ORBITER
  - 2 MAN AIRLOCK
  - 3 AIRLOCK PRESSURIZATIONS

ORBITER EVA CONFIGURATION



Δ EVA REQUIREMENTS
MORE THAN 3 EVA'S/MISSION

17.1 LB O_2	AIRLOCK REPRESS.	2.5 FT^3
8.3 LB N_2	PREBREATHING	
20 LB H_2O	EMU RECHARGE	

MORE THAN 2 EMU'S

11 FT^3 STOWAGE EACH EMU

Figure 38. EVA

Space Station Configuration

The functional elements required to support space sciences and construction, and the build-up sequence of these elements, are illustrated in Figure 39. The early years utilize the extended-duration orbiters; this was described in the previous section. The elements required are: (1) a power module, (2) a mission equipment module, (3) a cargo module, (4) a core module, (5) a habitability module, and (6) a combination habitability and laboratory module.

Power Module. The first element required is a power module. This module provides power to the extended duration Orbiter as discussed earlier. This module also has the capability to become the initial element in the Space Station. Consequently, the module must contain those subsystems that will provide it with the capability to remain in orbit, i.e., GN&C, RCS, thermal, etc. The initial power module is sized to produce 25 kW continuously with the capability to increase the power output to 50 kW. A typical power demand is illustrated in Figure 40. Two sizing concepts were investigated. The first concept would put the largest module in orbit, but only deploy enough array to meet the demand. By this concept, one size solar array only would be developed and would replace the initial array when required. This concept proved to be inefficient as illustrated. The largest array possible to place into orbit by the Shuttle could only provide three years of service even when sequentially deployed.

The second concept investigated provides a 25 kW solar array in the first 3 years and another module with a 50 kW capacity is placed into Orbiter for a 7 year period. The latter concept was pursued and the configuration of the initial module is illustrated in Figure 41.

Mission Equipment Module. This module was developed to provide facilities for various operations. The major areas of operation were the containerless processing facilities used to produce crystals, a biological processing facility, a direct solidification manufacturing facility used for the production of magnets, and a life sciences facility. Supporting services for these major functions included a biological analysis facility, a common data analysis console, a photo lab and film viewer, and an optical calibration laboratory. Consoles for sensor control of solar terrestrial observations was also provided. The module was designed to accommodate expansion of the major operations facilities. Figure 42 illustrates the facilities arrangement in the module and the changes as required for the increased operations activities. The final stage of the facility has additional storage capability as the driving requirements. This requirement was accomplished by placing the life sciences facility in the second habitability module. The additional volume created by the removal of the life sciences facilities provides the additional volume required for operations storage. The module is pressurizable and is designed to be operational in a shirt sleeve environment. All of the atmospheric control is provided by the Orbiter in the early phases of the program and later by the Space Station. The heat rejection is provided by the module with radiators around the outside perimeter of the module.

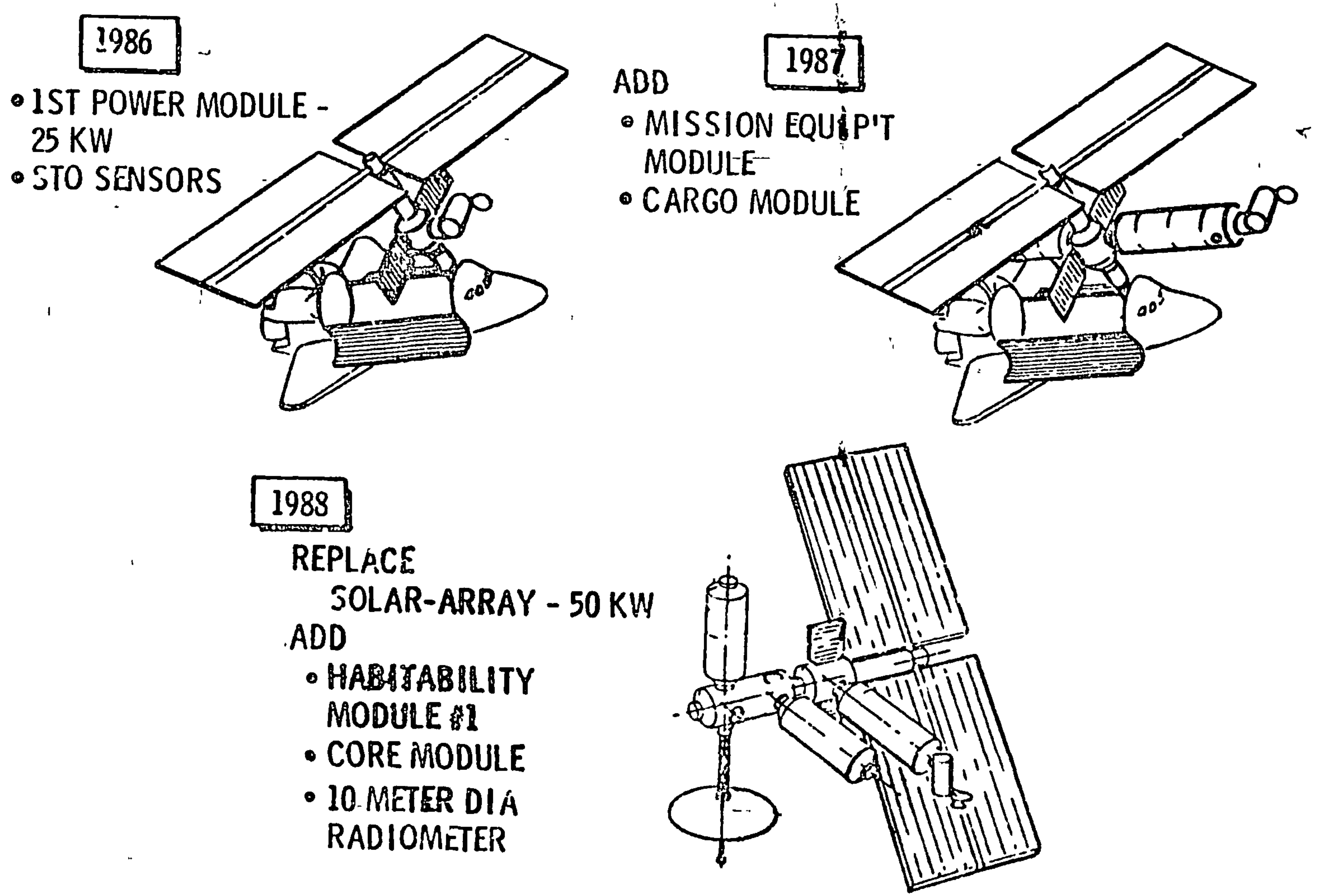


Figure 39. Space Station Build-Up

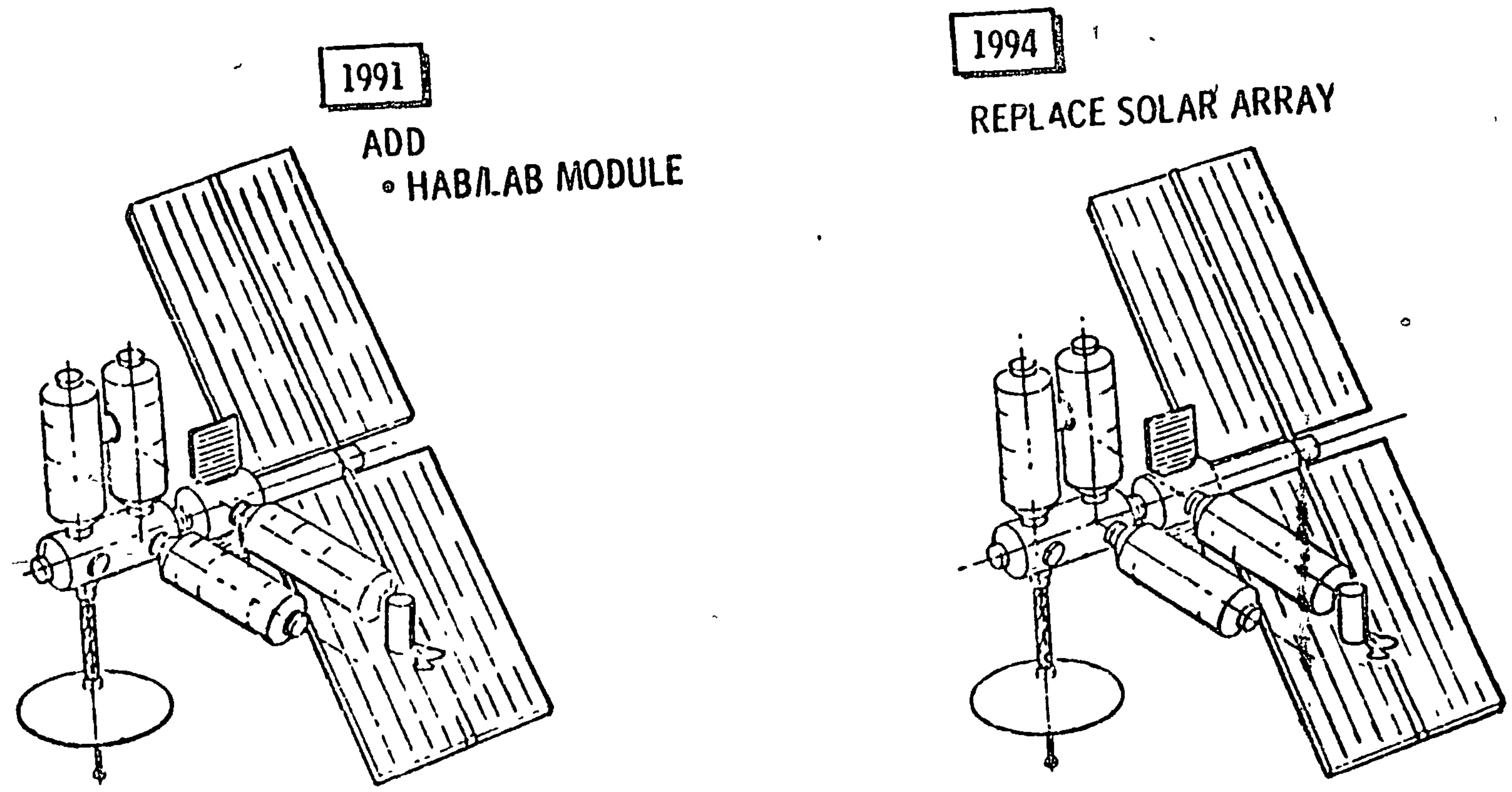
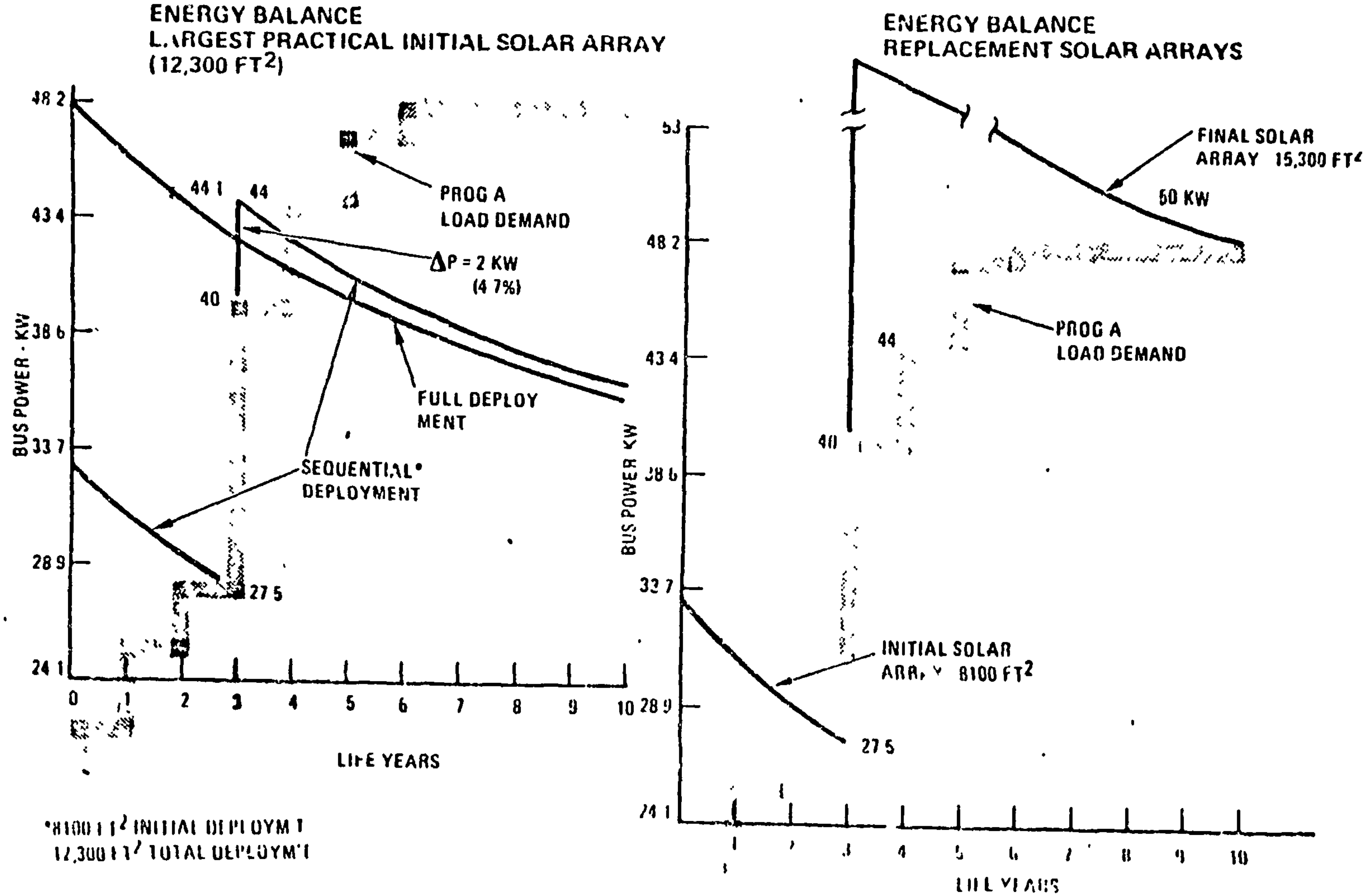


Figure 39. Space Station Build-Up (Continued)



*8100 FT2 INITIAL DEPLOYMENT
12,300 FT2 TOTAL DEPLOYMENT

Figure 40. Solar Array Sizing

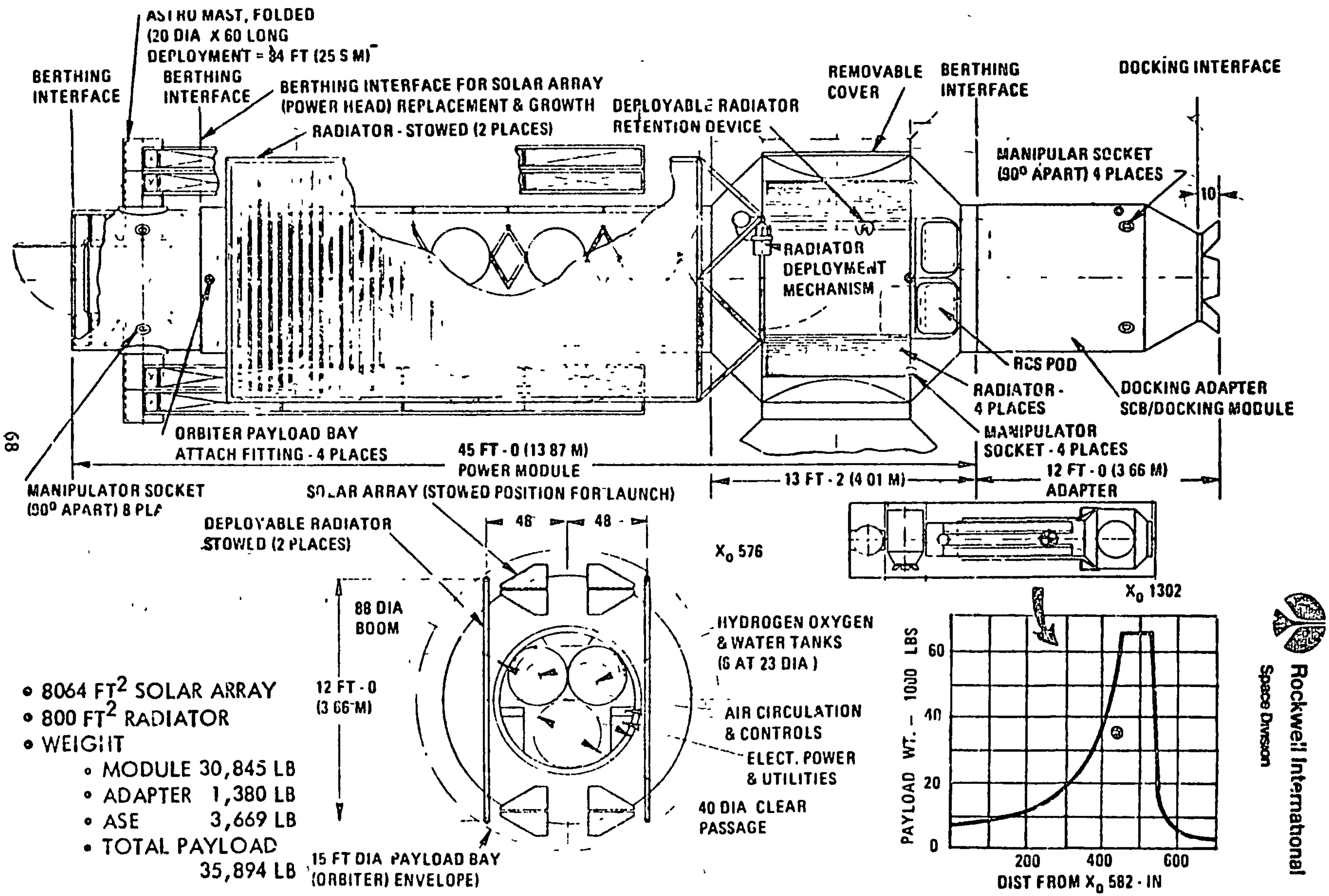
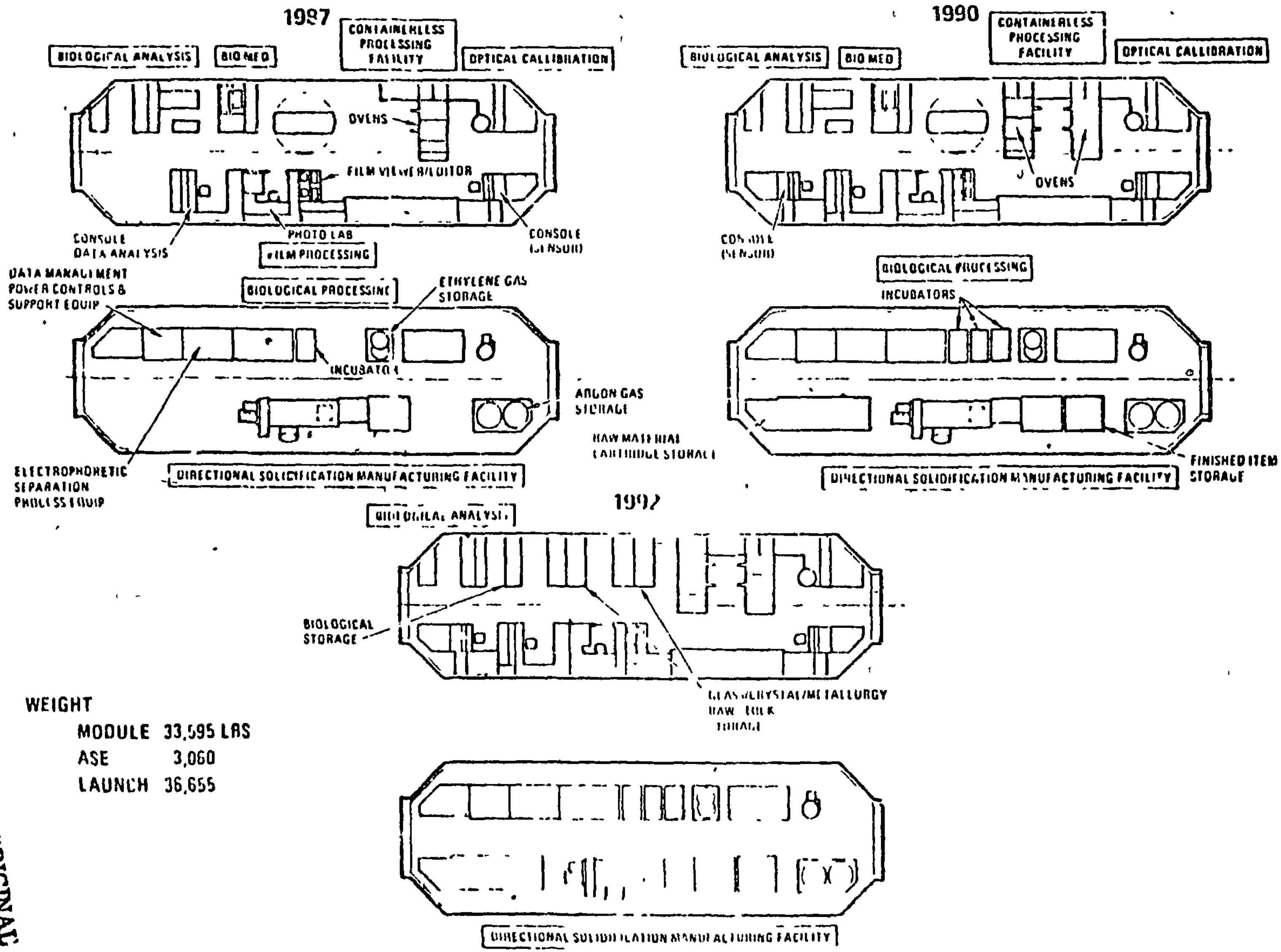


Figure 41. Initial Power Module



WEIGHT

MODULE	33,595 LBS
ASE	3,060
LAUNCH	36,655

Figure 42. Mission Equipment Module

Cargo Module. The requirement for a cargo module was first imposed in the program to support the mission equipment module. This module is utilized to transport materials and supplies for the operation of the space processing facilities within the mission equipment module. The module also provides the means of returning the completed products to earth. The module is pressurizable and operational in a shirt sleeve environment so that it is compatible with the mission equipment module and power module.

This same cargo module will be outfitted as a pantry unit to be used as part of the Space Station complex. This concept appears later in the program. The configuration of the module is illustrated in Figure 43. All of the consumables necessary to operate the Space Station is carried in the cargo module including water and nitrogen.

Core Module. The core module is required when the space activities indicate the need for a permanently habitable facility. The core module provides the attaching facility for the habitability module and cargo module with provisions for future growth of both increased crew and increased operational facilities.

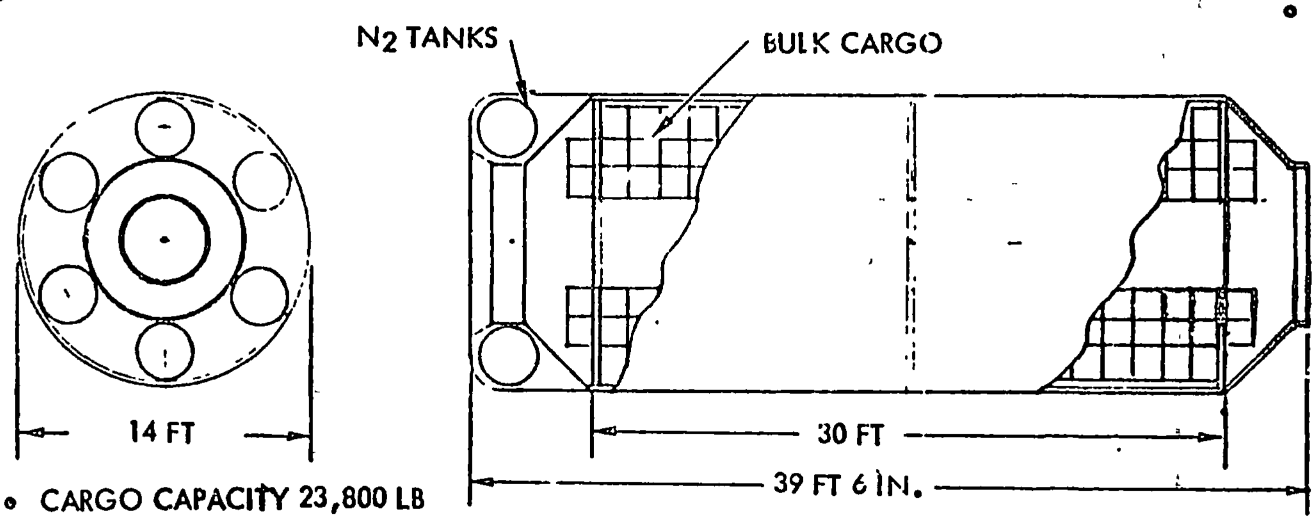
The core module provides the passage way between the modules. An EVA airlock located in the center of the module separates the module into two compartments. This separation provides the two pressurizable volumes that permit a safety retreat for emergency conditions. By outfitting the one compartment adjacent to the power module as an emergency volume containing emergency food, hygiene, and four sleep provisions, two independent habitable volumes are created. The first habitability module is placed on the core module that is furthest from the power module. The arrangement is shown in Figure 44.

The core module also contains a 25 KW secondary power installation utilizing fuel cells and electrolysis units. This power installation plus the 25 KW power capacity of the power module provides the capability of a 50 KW system. Redundancy is also provided with this arrangement.

An RCS cluster is also provided in the core module to supplement the unit in the power module. The H_2 and O_2 propellant for these engines are provided from the electrolysis units.

Habitability Module. The first of two habitability modules required is configured to provide accommodations for nine crew. The arrangement of the module is illustrated in Figure 45. In addition to the crew accommodations a central control console is installed. This console controls and monitors all subsystems.

The module is divided into two compartments identical to the mission equipment module. The lower compartment contains the ECLSS subsystem, and the water management system. This module provides the atmospheric control for the total station. Radiators on the surface of the skin provide the heat rejection capability for the subsystem equipment.



- CARGO CAPACITY 23,800 LB
- LAUNCH WEIGHT 40,000 LB

Figure 43. Cargo Module

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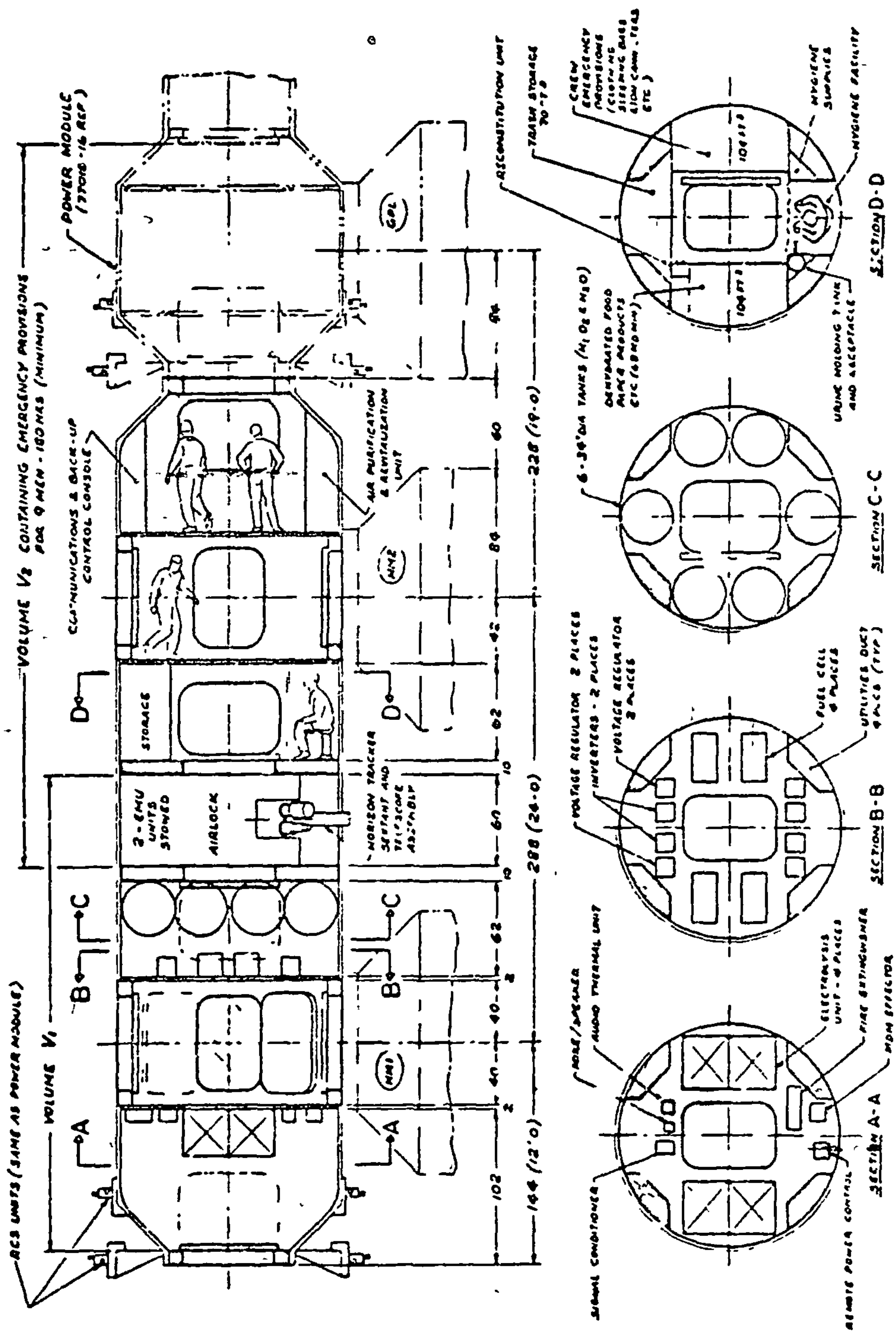

Figure 44. Core Module

- INITIAL 9 CREW
- 30-DAY CONSUMMABLES STORAGE CAPACITY

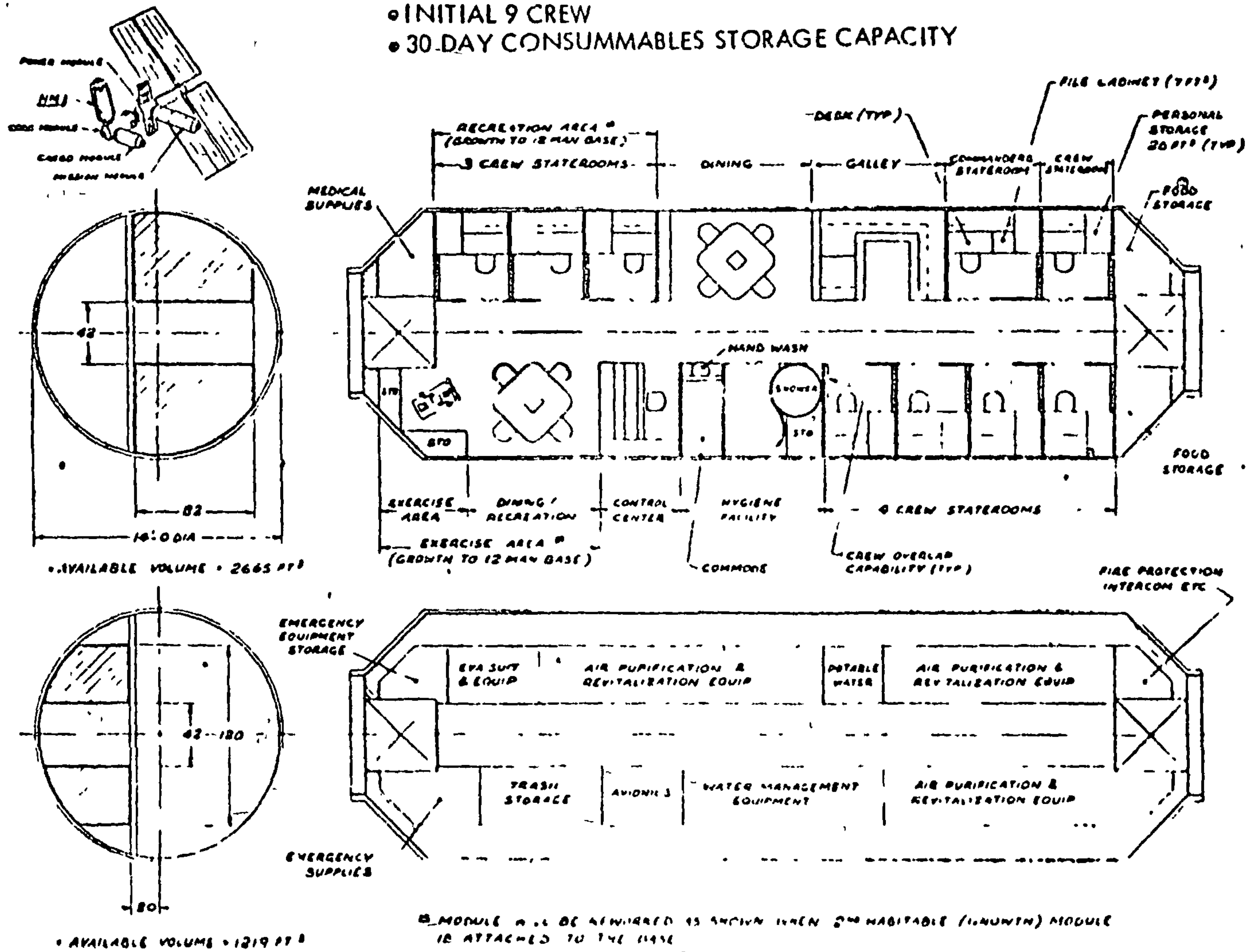

Figure 45. Habitability Module No. 1

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A second habitability module - Figure 46 , is planned for later in the program. This module is required to accommodate additional crew - up to twelve total. This module is outfitted to accommodate six crew with the life sciences and medical treatment facility. While the first habitability module is reconfigured to accommodate the other six crewmen and upgrade the galley and dining areas to accommodate the total crew of twelve.

The lower section of the second habitability module also contains the ECLSS and water management subsystems, thus creating a redundant arrangement within the station complex. This second habitability module is placed on the opposite side of the airlock from the first habitability module. This arrangement therefore provides equivalent functions in either pressurizable volume.

Commonality. Of the six modules just described, four have identical shell structures - habitability modules, cargo module and mission equipment module. The cargo module is shorter than the habitability module — 38 feet versus 28 feet — but the basic shell is identical. The core module and the power module have identical shell structures. Therefore, only two different types of shell structures are required.

Space Station Complex. The Space Station that evolved from this program has the capability to accommodate a crew of twelve, has 50 kW of electrical power available and accommodates various space processing activities, and some functions of the solar terrestrial observatory functions. Of the eleven berthing ports available, two are utilized for the habitability modules, two ports are assigned to cargo module berthing, one port accommodates the space processing facility, one port accommodates the solar terrestrial sensor package, and one accommodates a 10-meter diameter solar terrestrial antenna. One port is also allocated for Orbiter berthing. Two ports, therefore, are unassigned and can be utilized for berthing other modules and as servicing ports for free flying modules.

Space Station Facility Using the Shuttle External Tank

The use of the Shuttle external tank (ET) as a space station element was also studied in-house by Rockwell and was the configuration recommended by Grumman in their contracted Space Station studies* Also, the University of Alabama Summer Study at MSFC recommended use of the ET.

Grumman Space Station

The following was taken from the Grumman report* and is a summary of their system. The key feature of their concept is that the ET is used as a construction atrongback and no use is made of the internal volume of the ET.

The process of growth of the Space Station is illustrated in Figure 47. An Orbiter brings its external tank into orbit instead of jettisoning it prior to orbital insertion. The tank has been modified externally before launch to

*Space Station Systems Analysis Study, Final Report, Executive Summary, Grumman Aerospace Corporation Report No. NSS-SS-RP022 (July 27, 1977).

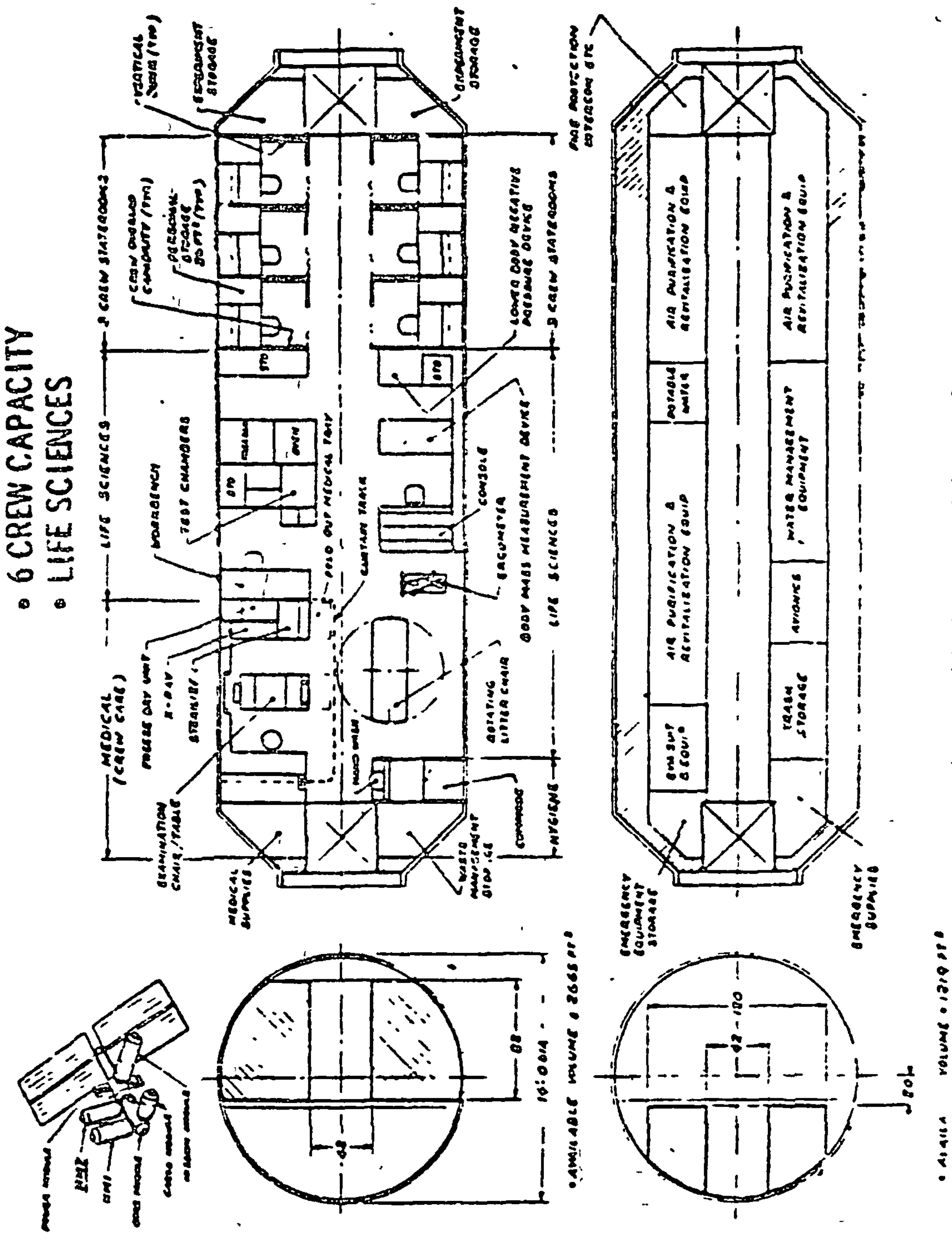

Figure 46. Habitability Module No. 2

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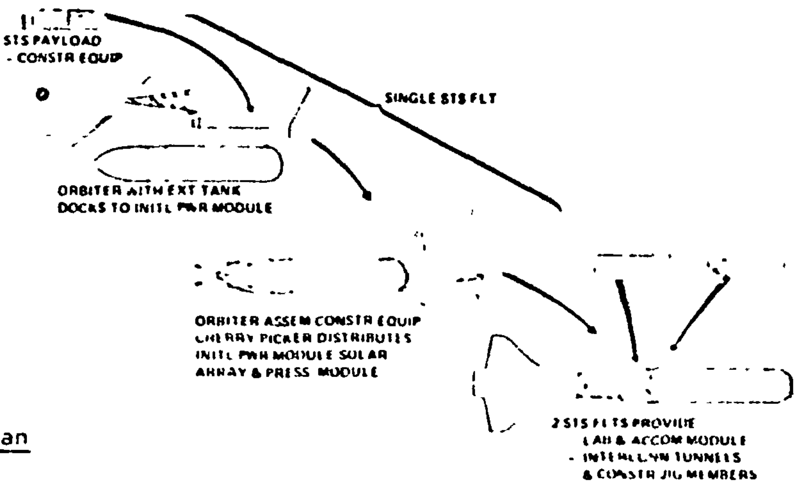


Grumman

Figure 47. SCB Early-Tended Growth Sequence

provide anchor points and two rails for the mobile Cherry Picker. Once the Orbiter/tank is docked to the IPM, the Cherry Picker carriage is deployed and attached to the rails of the external tank, using the Orbiter RMS. Then the remainder of the Cherry Picker is assembled to its carriage. The Cherry Picker is then used to build a short extension tower on the aft end of the tank and relocates the initial power module (IPM) solar array and its original tower there, adding a fifth SEPS-type solar array in the process.

A total of three flights, including that for the IPM completes the growth to an early-tended space construction base (SCB) with laboratory and habitation modules.

The following four key technical and programmatic features result from our approach in defining the growth from IPM to tended SCB:

1. Increase mission capability by adding the construction system before the provisions for further space manufacturing development. This alternative was chosen for two reasons:

    - Construction activity permits increased SCB power, SPS development, and public service platform (PSP)

    - Two main construction system elements have more than construction functions — the external tank workbench provides a rugged, large area, structural spine on which all subsequent additions accrete and the Cherry Picker provides far-reaching mobility for all external operations

2. Meet the steadily increasing power demand by building an advanced power module rather than adding more SEPS-type solar arrays. This choice promotes the development of lighter, lower cost, automatically

fabricated thin-film solar blanket. In addition, it provides synergistic support for the SPS Development Program, with light space structure fabrication and assembly experience, and by making available a power module building block suitable for space power development assembly (SPDA) multiple assembly.

3. Use 7-m long Spacelab modules, suitably modified as pressure modules for laboratories, habitation and subsystems in both LEO and GEO. A new 16-m long module would allow more flexible internal arrangements but the Spacelab module costs about $130 million less.

4. The external-tank workbench concept is chosen for the space platform on the basis of its:

   - Rapid availability after launch
   - Strength, rigidity and size
   - Precision mounts of rails and hard points
   - Large external *parking* area
   - Linear inertia characteristics favoring gravity gradient flight
   - Low Payload weight penalty and zero payload volume penalty
   - Potentially useful internal volume

In the following subsection we review the early construction activity, then describe the major features of the construction system.

Construction System

The construction tasks occupying the mid 1980's are summarized in Figure 48. Starting in early 1986, the tended SCB, powered by SEPS solar arrays, constructs an advanced power module (APM). Upon completion, this first APM of 250-kW 118-v solar output takes over the SCB power supply duties from the SEPS arrays. Following this, SPDA No. 1 is constructed, tested while still attached to the SCB, and then launched as a free-flyer for further tests in LEO. At this stage, SPDA No. 1 incorporates development antennas and a pair of 250-kW APM's, running at 20/40 kv. While these tests continue, PSP No. 1 is assembled, checked out, fitted with interim upper stage (IUS) solid rockets, and despatched to its operating station in GEO. Next, with an increase of construction tempo at the start of the manned SCB phase, three more pairs of APM's are fabricated, then, driven by their own flight control/propulsion subsystems, ferried to the free-flying SPDA and docked to it. When this assembly demonstration is complete the SPDA, now grown to the 2 Mw power level, is propelled by an IUS SRM to GEO, unmanned.

The heart of the SCB construction system is the single modified external tank. See Figure 49. The tank modifications — carried out on the ground before STS assembly and launch — are relatively simple. They consist of the

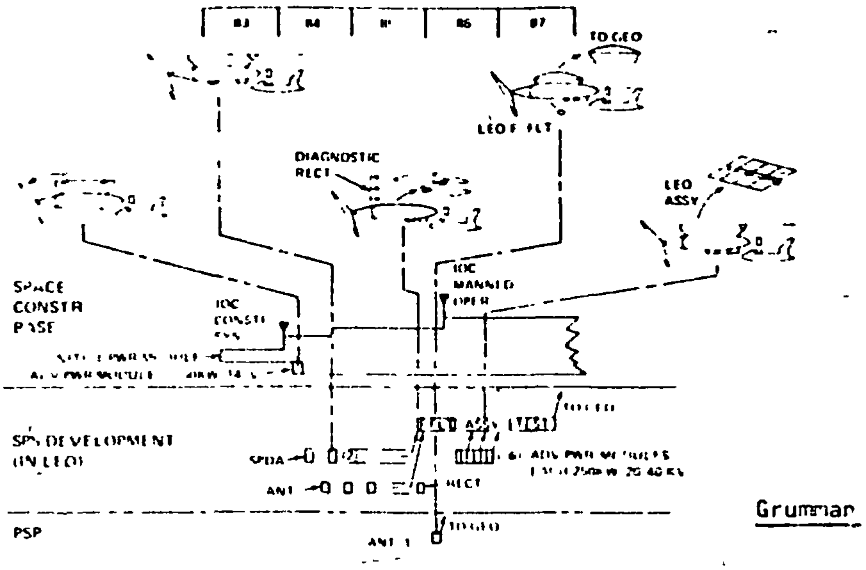
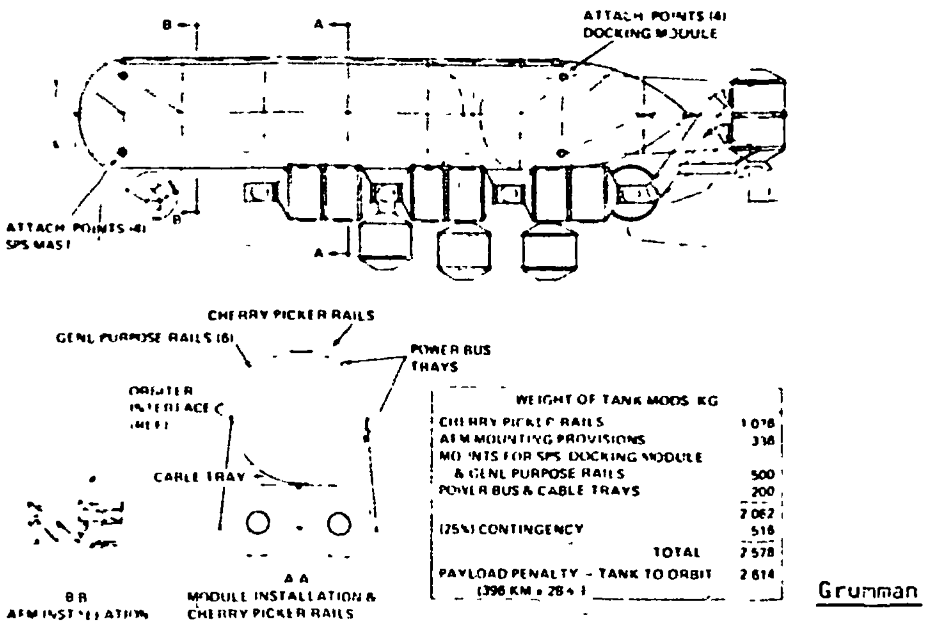


Figure 48. SCB Construction Activity



WEIGHT OF TANK MODS KG	
CHERRY PICKER RAILS	1 078
AEM MOUNTING PROVISIONS	338
MOUNTS FOR SPS DOCKING MODULE & GENL PURPOSE RAILS	500
POWER BUS & CABLE TRAYS	200
	2 062
(25%) CONTINGENCY	516
TOTAL	2 578
PAYLOAD PENALTY – TANK TO ORBIT (396 KM • 28.4)	2 614

Figure 49. External Tank Structural Modifications

following additions, running approximately the full length of the tank.

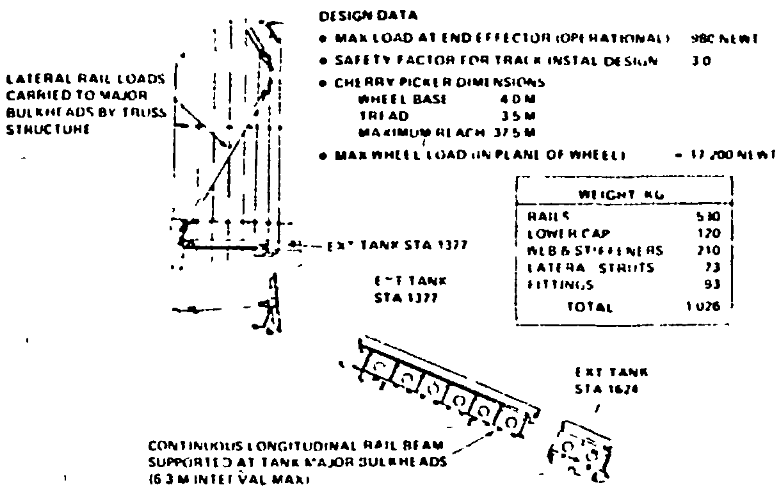
- Two rails for the Cherry Pickers
- Six general purpose mounting rails with pickup points at regular intervals
- Two power bus trays
- One cable tray

As shown, the total weight of these modifications is about 2,600 kg including contingency. When a similar weight is added, which represents the payload reduction penalty previously described for bringing an external tank all the way to the 396-km/28-1/2° orbit, the total equivalent payload weight for this 45-m long workbench is 5,200 kg.

During Part 2, we concluded that the great majority of structural components to be handled by the Cherry Pickers would fall below 1,000 kg mass. On this basis, a maximum load at the tip of the end effector of 980 newtons (100 kg force) represents little or no inhibition on the speed of construction. The Cherry Picker rails have been sized for three times this load and the loads have been carried through to the major tank frames (~ 6 m apart) without depending on the smaller, intermediate, frames (see Figure 50).

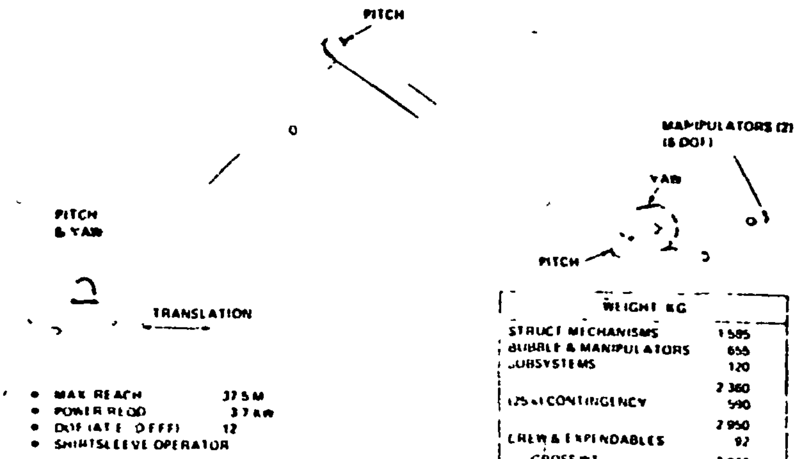
By mounting these rails on the tank as a ground factory task, potential alignment/waviness problems of space assembly of a rail track will be avoided.

The Cherry Picker carriage (see Figure 51) captures these rails between four pairs of wheels and translation along the track provides the first of twelve degrees of freedom available at the manipulator end-effector wrists.



Grumman

Figure 50. Cherry Picker Rail Installation



WEIGHT KG	
STRUCT MECHANISMS	1585
BUBBLE & MANIPULATORS	655
SUBSYSTEMS	120
	2 360
(25%) CONTINGENCY	590
	2 950
CREW & EXPENDABLES	92
GROSS WT	1042

Grumman

Figure 51. Cherry Picker

A pressurized bubble mounts the two short manipulators and provides a shirt sleeve environment for the Cherry Picker operator. Access to the bubble is through a berthing port which can be positioned and joined to a similar port in the tunnel attached to the accommodations module.

As shown earlier, the automatic fabrication module or *beam builder* is mounted athwartships on the external tank — opposite the Cherry Picker rails. Current design studies have been aimed at an aluminum (2219 T6 or 2026 T3) beam builder that will fit upright in the Orbiter cargo bay. This machine is necessarily short (4.3 m) weighs about 3,400 kg and consumes about 1.7 kW at 1-m/min building rate. Previous studies indicated that SPS antenna structures will probably be of composite material (e.g., graphite/epoxy or graphite/polyethersulfone). A beam builder for this type of material would be mechanically simpler, somewhat longer, would weigh about 2,800 kg and, because of its material heating needs, would consume 4.5 kW at 1 m/min.

We have made provision for one beam builder in the construction system, and have allowed for the mass of the heavier one and the power requirements of the composite beam builder. There is ample room for both should they be needed.

Rockwell External Tank Construction

On each Shuttle flight, the external tank (ET) almost reaches orbital velocity. Preliminary calculations indicate that an ET could be modified and launched into orbit with an unloaded Orbiter (except for OMS kits). In the design shown in Figure 52, the aft bulkhead of the O_2 tank is duplicated as the forward bulkhead, and a straight section is added so that total volume remains the same. The forward cone is reconfigured into a docking section and three stories of living/working area, each nearly 27 feet in diameter. Basic Shuttle Orbiter subsystems are installed, and are operated by Orbiter software. In addition, new long-duration life support equipment is used. On

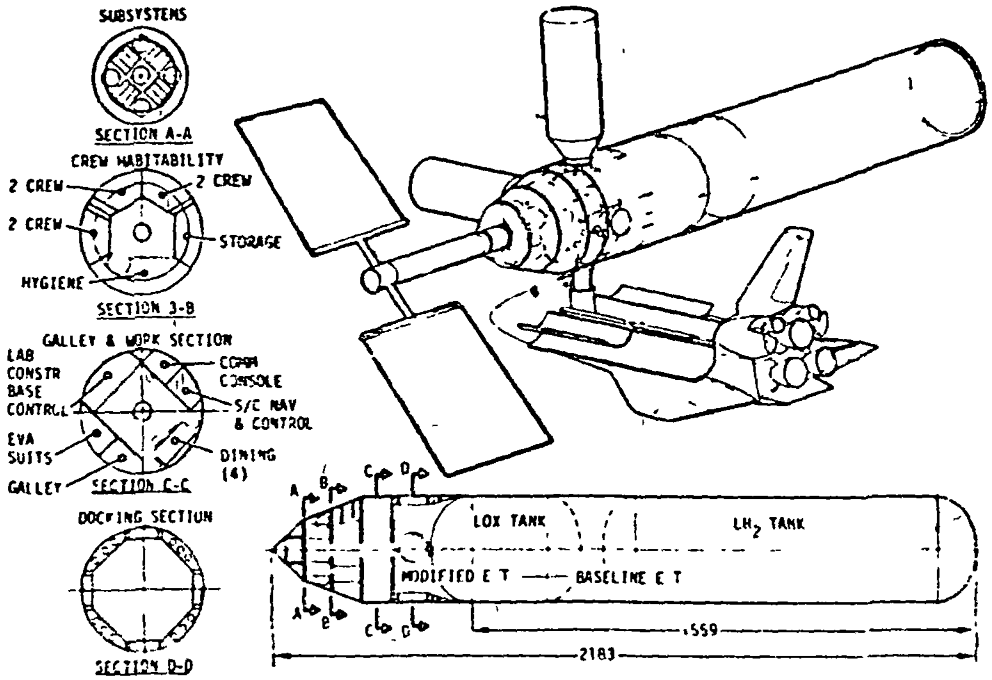


Figure 52. External Tank Construction Base

orbit the O_2 tank is opened and pressurized for habitability, and the aft bulkhead of the H_2 tank is removed by explosive charges (like the SLA on Apollo). The O_2 tank can now house free-floating space manufacturing items, the outfitted floors can be a habitat and control center, and the H_2 tank (never pressurized) can function as a warehouse, machinery yard, and construction platform. The ET construction base (ETCB) docks to a 25-kW power module which is already on orbit, and Spacelabs can dock to the docking ports and receive the same interface support that they do when in the Orbiter bay. Redundant equipment, supplies, and mission equipment can be brought up on separate Shuttle flights. If slightly more launch energy is needed for this one launch, the fill procedures can probably be modified at KSC to subcool the LH_2 and LO_2 for more total propellant availability.

As shown in Figure 53, the aft bulkhead of the ETCB can be explosively separated on orbit, leaving the internal volume of the hydrogen tank exposed to the space environment. Fittings and tie-downs can then be placed on both the inside and outside of the tank. Figure 54 shows this space station performing construction operations in LEO.

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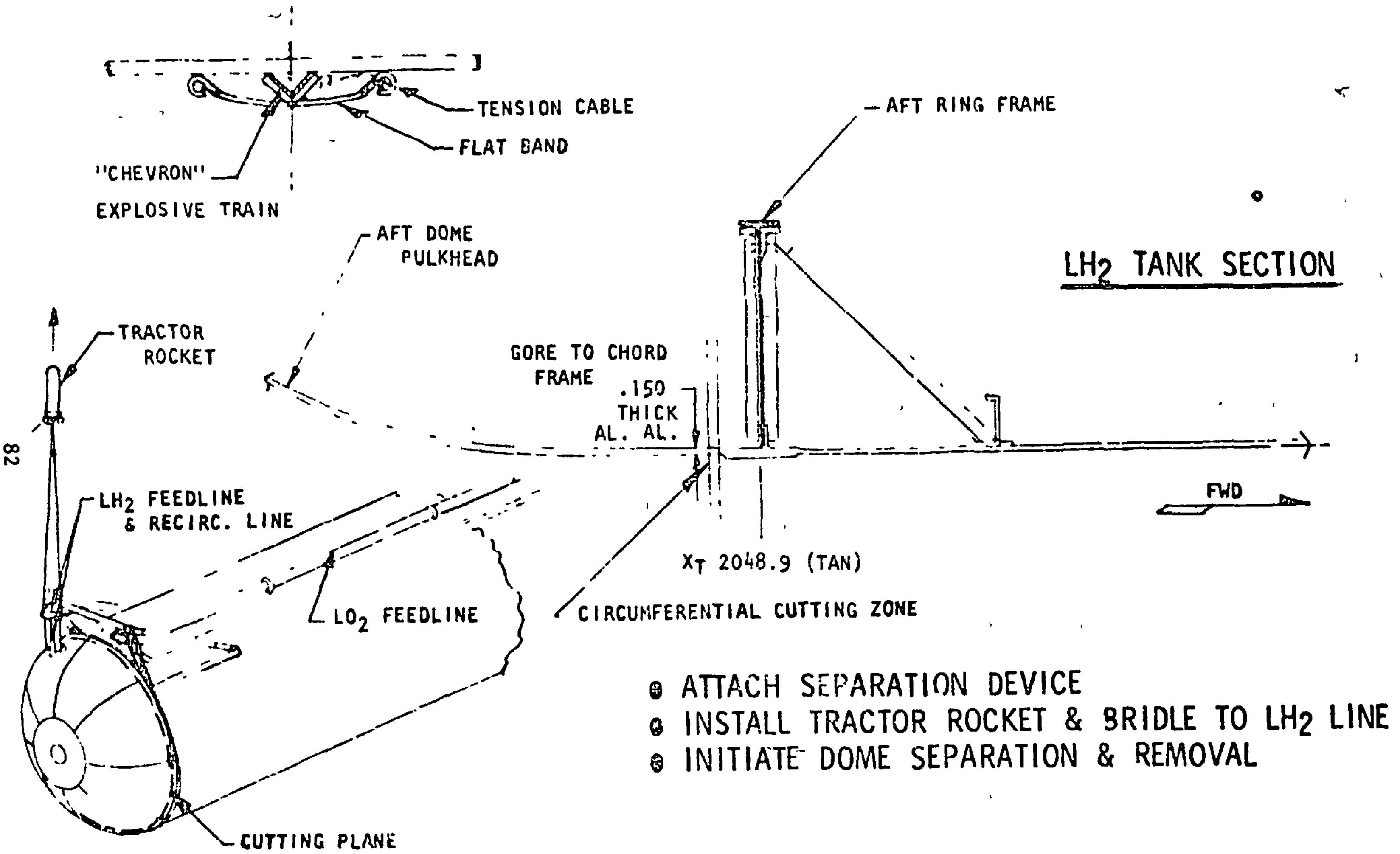

Figure 53. Aft Dome Bulkhead Separation Concept

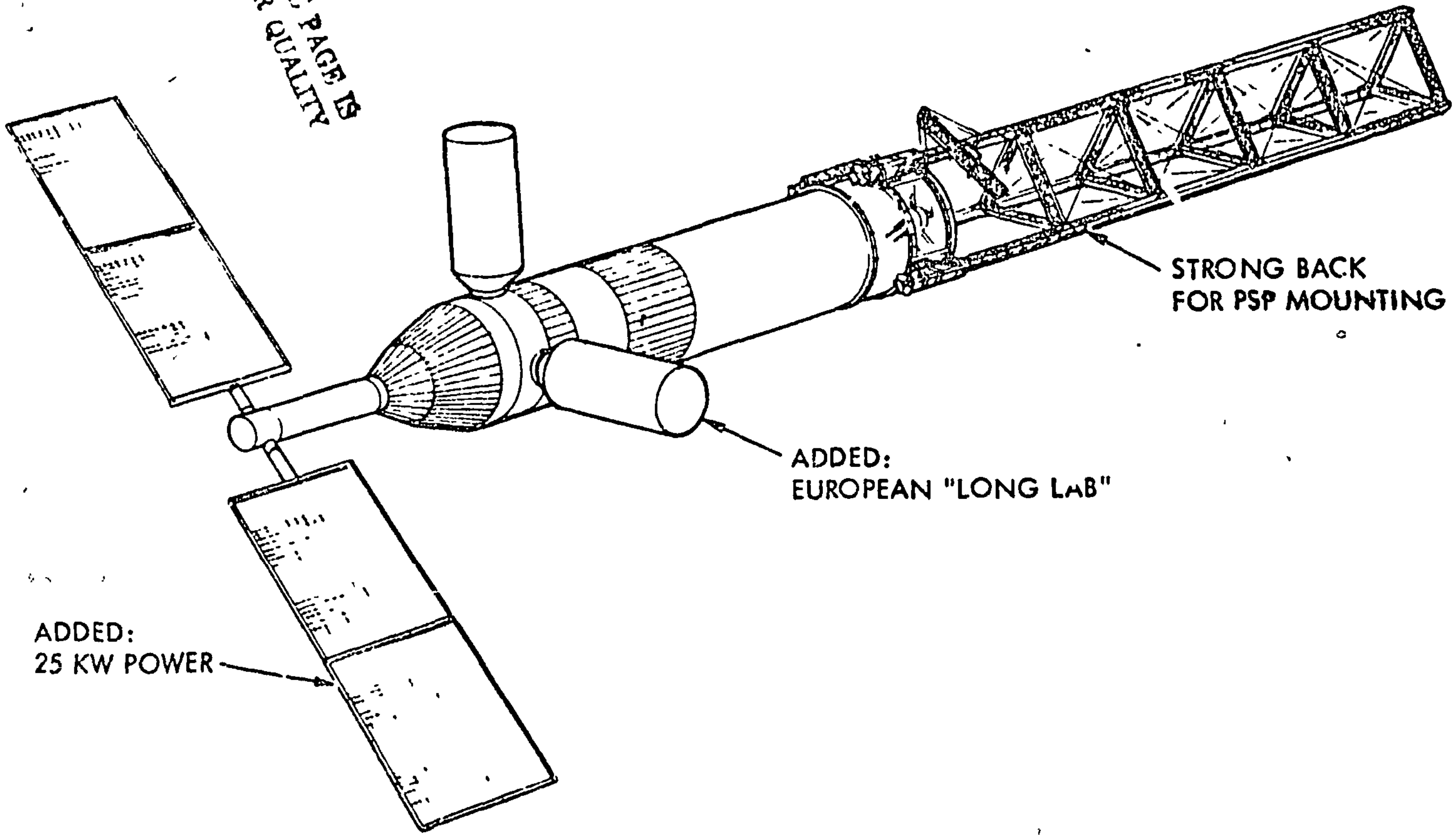

Figure 54. LEO Operations of ETCB

SPACE PROCESSING FACILITIES

One of the major new *space industrialization* initiatives identified by various investigators is the development of one or more on-orbit processing facilities for the manufacture of certain very high-quality products. Although orbital transportation costs are high, the special environmental properties of space — zero-g, hard vacuum, low vibration, etc. — are so beneficial that the production of several dozen different products in space appears to be economically attractive.

It is obvious that the orbital location of such a space processing facility will have an important impact on its intrinsic performance characteristics. In particular, the transportation costs and the solar illumination are strongly dependent upon the selected location. If the facility can be located in full sunlight most of the time, the need for energy storage can be greatly reduced. However, in general, those areas in space that have the most solar illumination tend to be relatively inaccessible. The polar plot at the top of Figure 55 pinpoints a collection of candidate locations. The radial distance represents the altitude of the orbit and the angular location represents its inclination. The bar chart in the lower portion of the figure represents the fraction of time each candidate facility will spend in full sunlight. Note that two of the locations are illuminated almost continuously. Low-altitude sun-synchronous satellites in dawn-dusk orbits receive full illumination about 98 percent of the time,* geosynchronous satellites are illuminated more than 99 percent of the time. Though attractive from the viewpoint of nearly continuous energy production, these special orbits are relatively inaccessible to the Space Shuttle. The Shuttle can carry, at most, only about 15,876 kg (35,00 lb) of payload into a low-altitude sun-synchronous orbit. Its geosynchronous capability (assuming the use of a properly-designed reusable upper stage) is about 3629 to 5443 kg (8000 to 12,000 lb). The Shuttle's payload capability for a 55° low-altitude orbit is improved considerably, but it still amounts to only 18,144 to 27,215 kg (40,000 to 60,000 lb). Therefore, since transportation costs will dominate the economics of space processing operations, it seems clear that a low-altitude 28.5° orbit [Shuttle payload capability = 29,483 kg (65,000 lb)] is by far the most viable selection. This is true despite the fact that the processing facilities will be sun-illuminated only 31 to 40 percent of the time.

Space Processing Facility

The space processing facility that was designed as a part of the *Space Industrialization* study effort is shown in Figure 56. As can be seen, it consists of two basic structural elements: a solar cell power array and a modified external tank (delivered into orbit in a earlier Shuttle flight). The solar array accommodates six gallium aluminum arsenide cell blankets that measure 16 meters by 14 meters. The structure is assembled from four space-manufactured beams that are connected to the interstage area of the external tank. The total length of each long beam is 106 meters.

Modifications to the external tank include an RCS/propulsion module docking to the forward end of the LOX tank, attachment brackets attached to the

*Continuous illumination is achieved if the orbital altitude is between 1389 and 3334 km (750 and 1800 nmi).

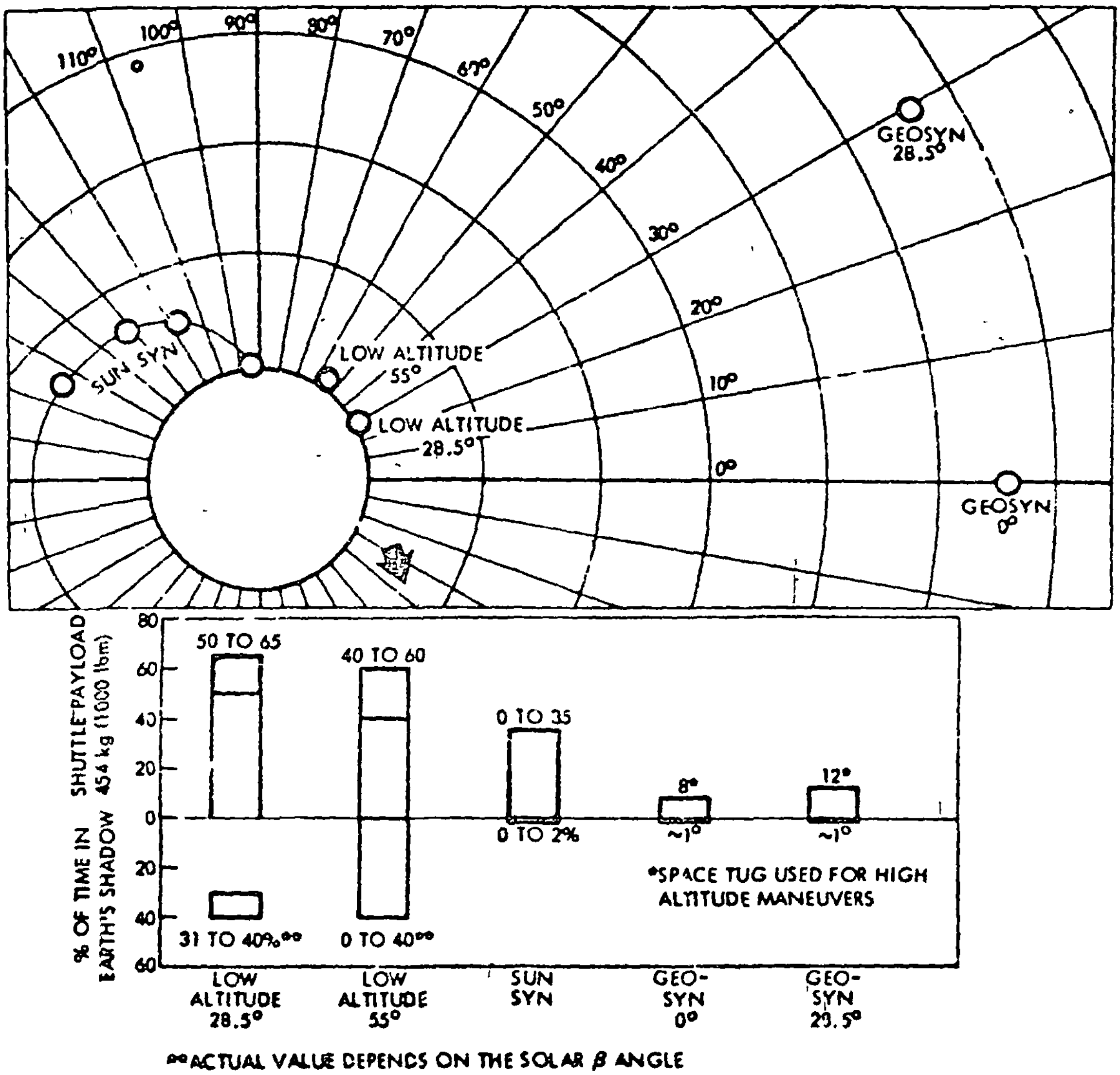

Figure 55. Orbital Location Trades

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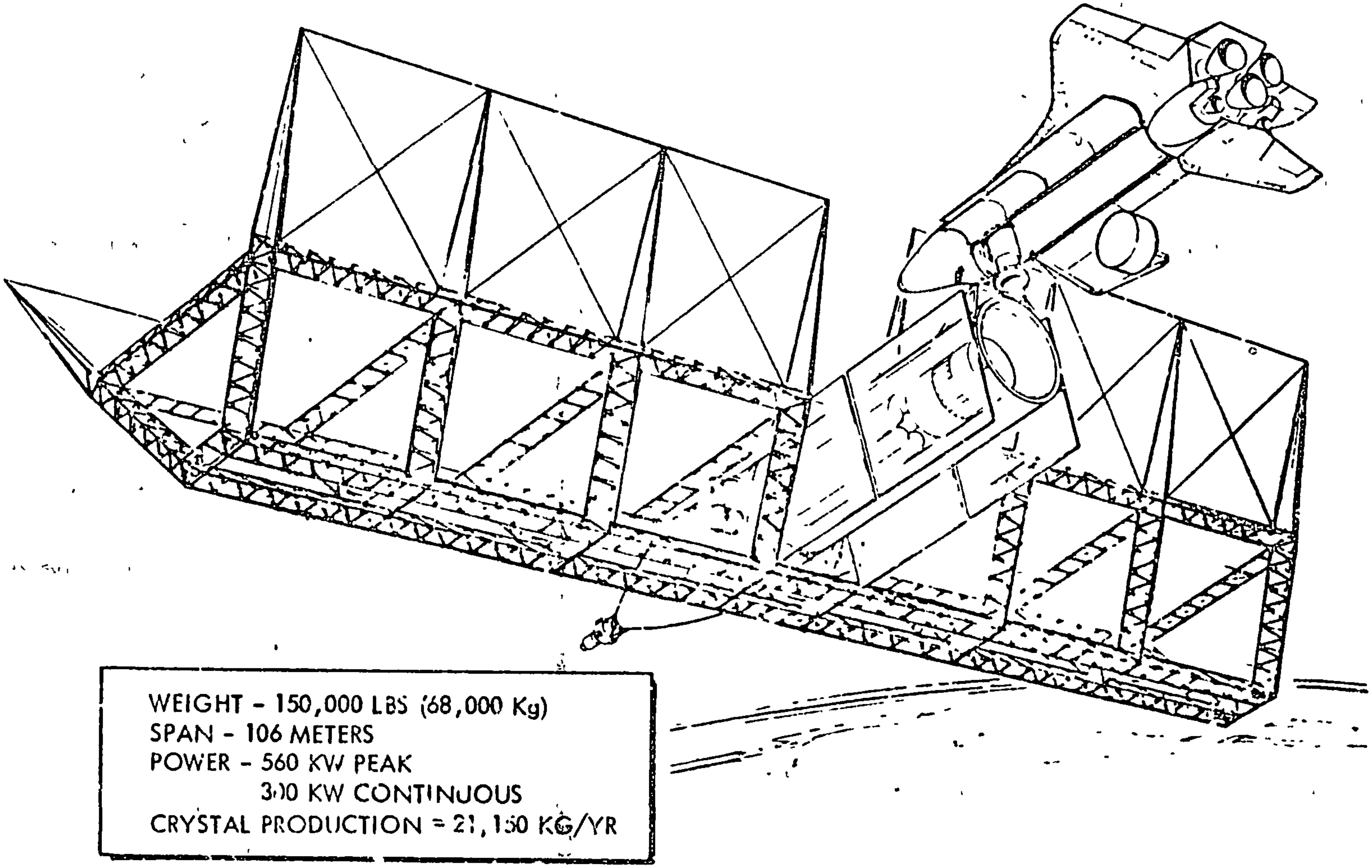


Figure 56. Space Processing Facility - External Tank Modification

inter-tank area, electrical and control wire harness and LH_2 tank connector panel, a docking ring (for the Orbiter) at the aft Orbiter support points and a system for jettisoning the aft dome of the LH_2 tank.

On-orbit, the entire configuration flies with the solar cell panels normal to the sun, providing a peak power of 560 kW. The interior of the LH_2 tank is configured for equipment insertion while on-orbit. For space processing, a continuous power level of 300 kW is available by utilizing $Ni-H_2$ batteries assembled in a four-meter diameter module. This battery module is 12 meters long. The remainder of available length (approximately 11 meters) in the LH_2 tank is reserved for various process equipment (furnaces, magazines, etc.). The present configuration is estimated to weigh approximately 68,000 kg, with the external tank included as 34,000 kg of this weight. The electrical battery module accounts for approximately 16,000 kg and the process hardware amounts to 7,500 kg. A raw material re-supply weight is estimated at 4,500 kg, including expendable process gases.

The presently configured facility is outfitted for *zone refining and crystal growth.* The fifteen furnaces are capable of producing 750 boules of finished product every 60 days. With Shuttle servicing of raw material magazines and return of finished product, the space processing facility is sized to yield 4500 boules per year. This is equivalent to 21,150 kg/year (46,636 lbs/year). Further extrapolation would lead to a total of 30 Shuttle flights per year to service 10 such processing factories, to yield over 200,000 kg of finished products.

Facility Design

The design of the space processing equipment was based on existing experimental units currently under development. The product size and associate power requirements, weight and process time were carefully adjusted in an effort to size the orbiting factory needed to contain a *production quantity* of process equipment. A few of the desirable characteristics for a Space Processing Facility can be listed as follows:

1. Solar array electric power should be utilized for processing. Limiting array size should correspond to technology available in the 1980 to 1990 time frame.

2. A platform or *hardback* should be furnished to support all process equipment.

3. Battery power should be utilized for peak loads and to maintain constant power even during the eclipse periods.

4. The design should be compatible with the Shuttle payload capability during on-orbit assembly and for periodic servicing and product transfer operations.

5. The facility should be completely automated and unmanned during a reasonable *batch process* period.

Analysis of a few viable process operations for power consumed helped in sizing the proposed hardware elements. However, this discrete design will undoubtedly be heavily modified in both layout and function once particular products and space environment processing have been proven experimentally.

General Arrangement

The facility shown on Figure 57 (Dwg. 78255-005) consists of two major elements: a solar cell array and a center structure derived from the ET.

A representative product, *Zone Refining and Crystal Growth of Silicon*, is examined in detail in order to show the equipment design and location within the facility. This particular process is considered to be representative of the many processes that could be carried out in space in a profitable way. Of course, yearly production levels and Shuttle servicing periods are expected to vary for each individual process.

Solar Cell Array

The solar array consists of four manufactured beams of triangular cross section, connected by several similar but shorter beam members at eight points along the span. An overall triangular section results in a center bay designed to accommodate the 8 meter diameter of the external tank. Overall dimensions are as follows: span = 106.66 meters; width (including reflector panels) = 32 meters.

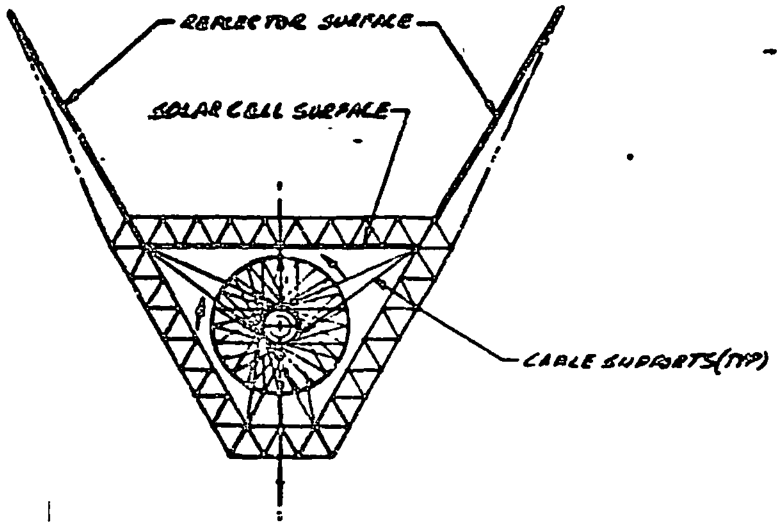
Six of the seven bays are identical from a structural viewpoint in that they utilize solar cell blankets that are 16 meters by 14 meters. The structural beams are configured to be held in position on three sides by the connecting struts and diagonal tension tapes. Auxiliary equipment, such as RCS packages and momentum wheels, are installed during on-orbit assembly.

Solar Cells and Blanket

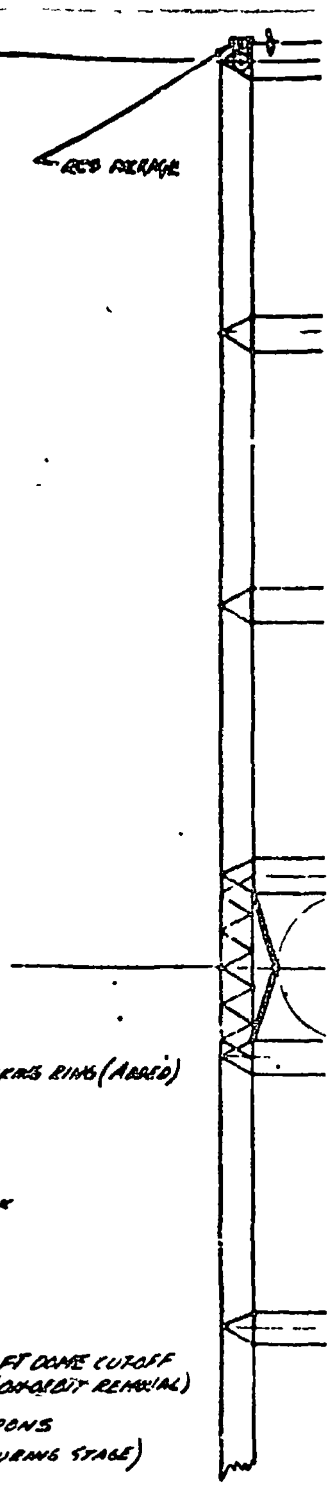
The upper face of the structure contains six identical bays which measure 16 by 14 meters. A blanket, containing the solar cells, is brought to the site (in a rolled condition) from the Shuttle and all four edges are installed by lacing them to the structure. The Space Processing Facility requires a large amount of electrical power; therefore, gallium aluminum arsenide cells were chosen with a concentration ratio of 2:1. Thin film substrate, similar to that envisioned in earlier SPS studies, was utilized. The total cell area was sized at 1344 met^2. The peak electric power to be expected from this array is 560 kW at end of life. However, the space processing demand should not be based on this maximum power level, but on a much lower continuous power capability of 300 kW. This reduction was necessary to provide for the effects of solar occultation, conversion losses during battery charging, power losses due to off-optimum sun angles and gradual cell degradation due to radiation damage.

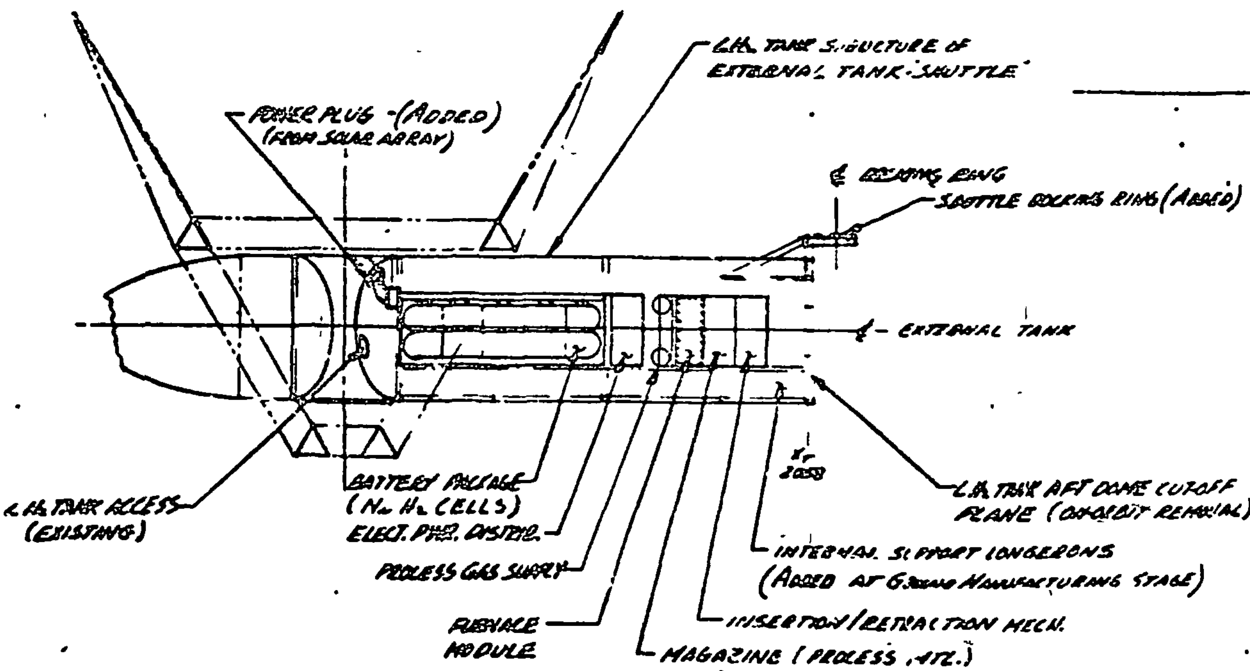
Side Reflectors

The solar array is provided with side reflectors canted at an angle of 60 degrees. These reflectors consist of a thin mylar film covered with a reflective coating. They are located on each side of the solar cell bays and



8 METER DIA MOMENTUM WHEEL – 2 PCS
(CABLE SUPPORTED)





ZONE REFINING CRYSTAL GROWTH FACILITY ARRANGEMENT

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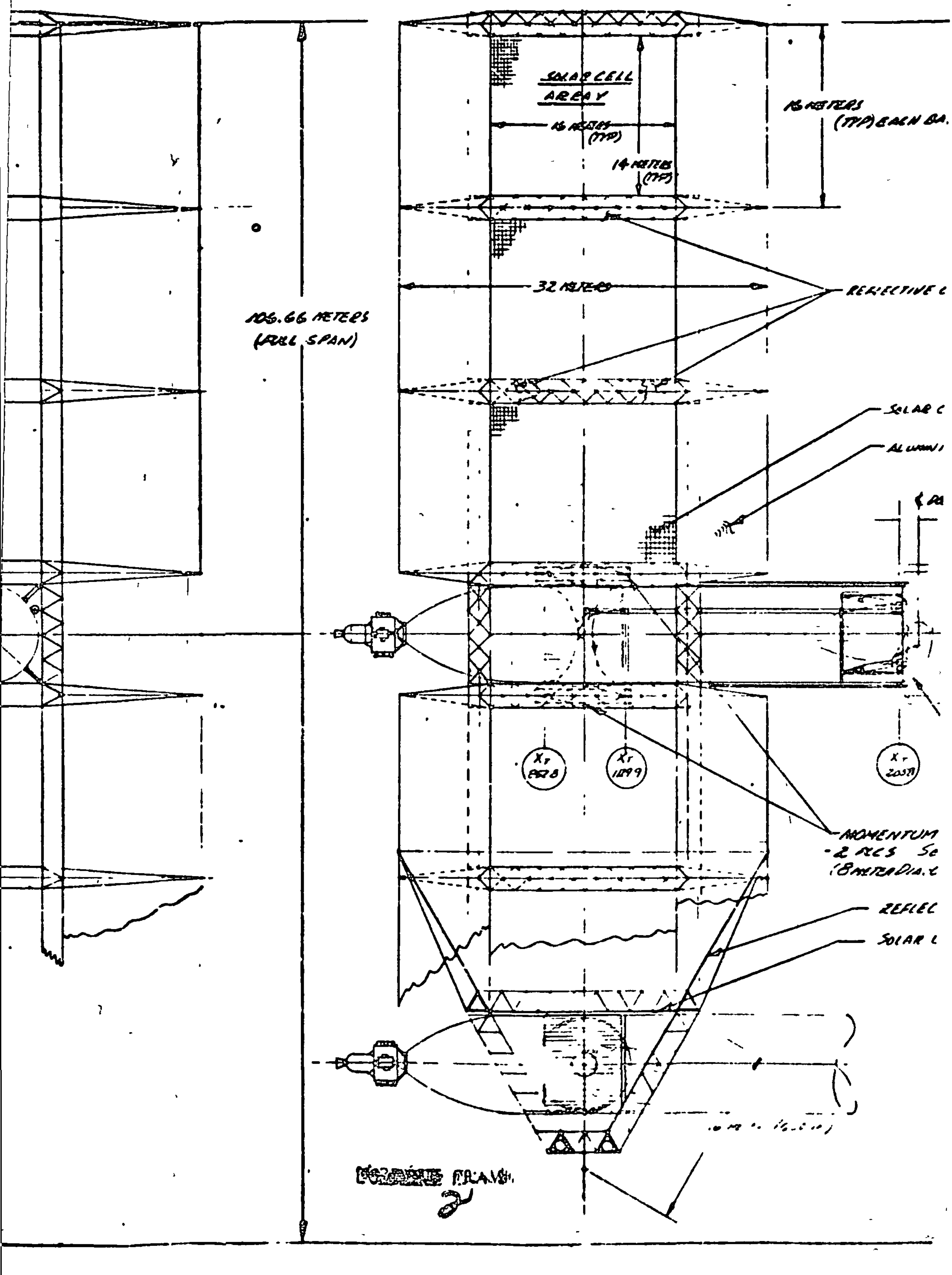

SOLAR CELL ARRAY
16 METERS (TYP)
14 METERS (TYP)
16 METERS (TYP) EACH BA.
32 METERS
REFLECTIVE C
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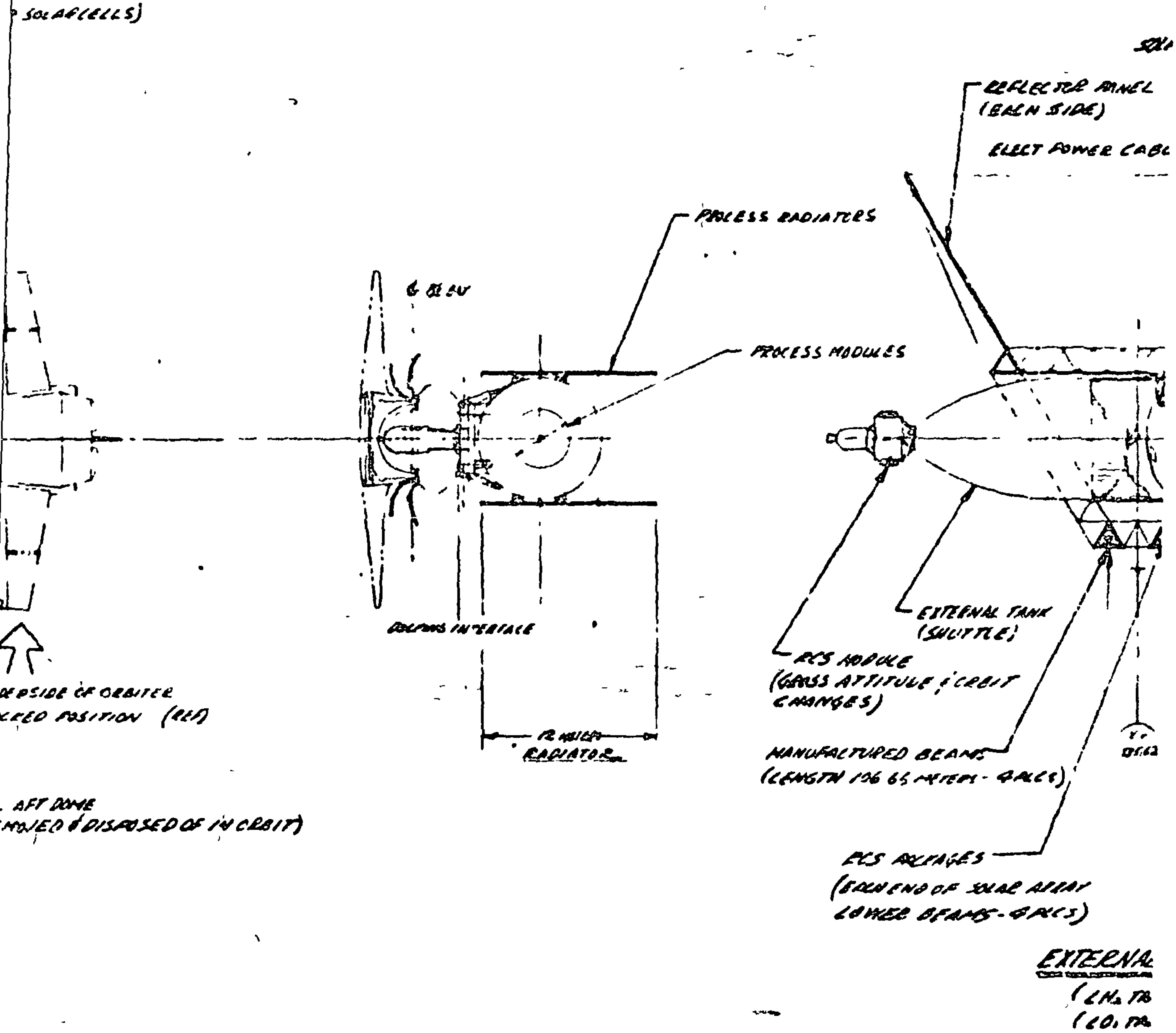
SOLAR CELLS)
REFLECTOR PANEL
(EACH SIDE)
ELECT POWER CABL
PROCESS RADIATORS
PROCESS MODULES
INTERFACE
12 METER
RADIATOR
EXTERNAL TANK
(SHUTTLE)
RCS MODULE
(GROSS ATTITUDE & ORBIT
CHANGES)
MANUFACTURED BEAMS
(LENGTH 106.65 METERS - 4 PCES)
RCS PACKAGES
(EACH END OF SOLAR ARRAY
LOWER BEAMS - 4 PCS)
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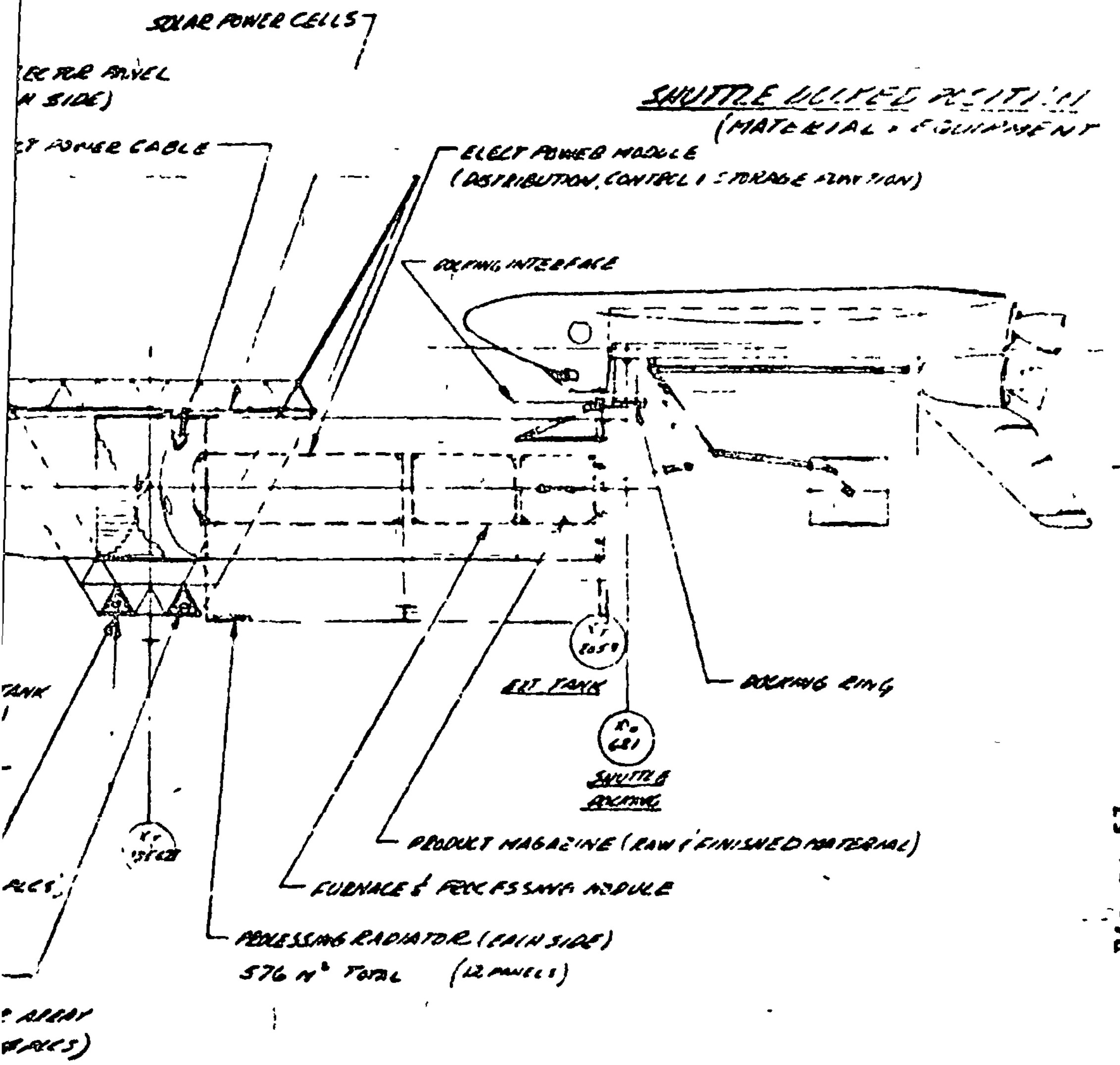
4



EXTERNAL TANK ORBITAL PROCESS FACILITY

(LH₂ TANK OPEN-END FOR EQUIPMENT & PROCESS MODULES)
(LO₂ TANK FOR CONTAMINANT STORAGE)
(SOLAR ARRAY POWERED - 580 KW EOL)

Figure 57.

ROCKWELL INTERNATIONAL CORPORATION
SPACE DIVISION

SPACE PROCESSING FACILITY

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they are supported by telescoping extension rods and wire bracing. The reflectors are sized to provide a 2:1 geometrical concentration ratio.

Electrical Power Generation

Each solar cell is connected in series and parallel combinations to a main electrical distribution harness which, in turn, is routed through a special penetration fitting mounted on the forward dome of the LH_2 tank. The installation of this penetration fitting is one of the few pre-launch modifications required on the tank. The wire harness is attached to the solar array structure and routed to the inter-tank structure area of the external tanks.

Basic External Tank Characteristics

The basic Shuttle external tank provides a *hard back* and containment structure for any process equipment envisioned for the time period of interest (1980 to 1990). The tank can be flown into orbit by adding a small extra impulse near the end of the Shuttle flight. In this way, the tank is brought to orbit rather than allowing it to re-enter the atmosphere. Once it is in orbit, it provides the structure for on-orbit assembly of the solar array.

Pre-Launch Modifications - External Tank

The following modifications to the external tank will be necessary prior to launch:

1. Establish a docking ring structure on the forward end of the LO_2 tank for later RCS module attachment.
2. Install support structure and brackets to the inter-tank structure for eventual attachment of solar array beams.
3. Install wiring harness and penetration panel on dome of LH_2 tank.
4. Attach longitudinal support beams in the LH_2 tank. Also add miscellaneous metal brackets and tie points internal to tank.
5. Affix external pyrotechnic cutting lines, additional controls, and tractor-type rocket to aft LH_2 dome.

All of the above listed modifications must be made in such a way that they do not interfere with the normal functioning of the Space Shuttle.

On-Orbit Modifications

Various on-orbit modifications are required to prepare the external tank for building up the processing facilities. Fundamentally these on-orbit operations consist of separating the Orbiter from the tank, activating the aft dome removal system, removing dome structure by firing of the tractor rocket, and using the Orbiter RMS to install a docking ring to the two external tank/Orbiter attach points for future Orbiter docking and servicing of the processing facility.

Exterior and Interior Additions to Processing Facility

External additions to the Space Processing Facility include the following:

1. Installation, balancing, and startup of two momentum wheels in the solar array cross sectional structure. These wheels are delivered in rim sections. The hub and the wire bracing are delivered by subsequent Shuttle flights and installed by EVA operations.
2. Reaction control packages, designed to be installed in both ends of the solar array lower beams, provide gross maneuver capability during the life of the vehicle. In addition, a large diameter (4 meters) package is docked to the forward end of the LO_2 tank. The larger module would be designed to provide sufficient propulsion to raise the assembly orbit to the desired processing altitude of 500 to 600 kilometers. These items are compatible in size and weight with Shuttle capabilities.
3. While the Shuttle is docked to the aft docking ring, its Remote Maneuvering System is utilized to extract, unfold and install two radiator panels to the side of the external tank. Existing fittings previously used for solid launch rockets are used to mount one edge of the radiator panel to the external tank. A total of 576 m^2 area or 288 meters per side is available for heat rejection.

Electrical Power Storage - Internal Package

Electrical energy storage is required to guarantee continuous processing even during eclipse periods. Of all the rechargeable battery systems, the nickel-hydrogen cell appears to be the most feasible for this application. The following assumptions helped in sizing and configuring the battery module:

1. Low earth orbit (30 minute eclipse)
2. Low inclination orbit
3. Battery temperature range 0° to 20°C
4. Battery load 500 kW (this corresponds to a 250 kWh storage requirement for the eclipse period)
5. Basic characteristics <u>do not</u> include charge/discharge control electronics weight and efficiencies.

The battery module design consists of 15 pressurized containers all within the four meter diameter compatible with the Shuttle payload bay; a length of approximately 480 inches and a total weight of 34,700 lbs. This ten-year life system will undoubtably be the subject of many design and economic trade-off studies as this energy storage technology progresses.

Structural Supports - Interior

A structural system within the LH_2 tank will be required to locate the equipment essentially on the centerline. The four-meter diameter modules are attached to two longitudinal beams (ground modifications) and stabilized by a network of cables. Electrical junction boxes, wire harness supports, heat pipe installations and insulation blankets are attached to a set of brackets which are attached to the tank prior to launch. A completely automated control system for electrical and thermal conditioning is installed in the same manner prior to installation of any space processing modules. Mechanical clamps and fasteners are utilized with existing internal tank structure to minimize the effect of adhesive material outgassing in the presence of any space processing operation.

Shuttle Service to Facility

The first few flights of the Shuttle to the processing facility will carry general factory equipment. Later flights will be dedicated to specific process equipment modules. After stable docking has been accomplished, all the modules and equipment may be inserted in the open end of the LH_2 tank. The processing facility has been designed to operate in an unmanned condition. However, maintenance of the external tank, the radiators, the momentum wheel, and the solar panels may also be accomplished by EVA operations. Replacement and servicing of RCS packages is to be accomplished by the Remote Maneuvering System (RMS).

Visits to the Space Processing Facility will eventually be scheduled to harvest a full load of processed material and will not interfere with normal processing. Specific processes will have periods of material change-out and the Shuttle may dock at these times.

Other Factory Capabilities

The Space Processing Factory is configured to accommodate a varied supply of specialized gases in tanks mounted on the internal structure. These gases will be used in specific space processes.

The LO_2 tank of the external tank will serve as a fully contained dumping facility. This containment function may be required to maintain a pure environment in space in the vicinity of the process modules. The LO_2 tank may also be useful for re-filling and use as a propellant tank in certain orbital transfer operations.

Space Processing Candidates

Processing of materials in space environment is still in its infancy. Experimental furnaces, levitation units and vapor transport devices are currently being designed for early Shuttle flights. The results of these experimental procedures will serve to guide future programs and product manufacturing toward a dedicated Space Manufacturing Facility.

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Many products, some not yet conceived, will be experimentally processed in space. The extension to a production facility will depend upon the enhanced quality and economic advantage gained by space processing.

The presently proposed Space Processing Facility has been designed to accomplish the melt zone refining of silicon crystals and crystal growth. The power requirements and the raw material weights have been tailored to fit within the capability of the proposed design.

This process and the associated designs are considered representative of other processing modules only in the sense of providing a basis for estimating the rough order of magnitude sizes, weights and costs that may be anticipated when space processing facilities reach operational status.

Zone Refining and Crystal Growth Concept

The design of zone refining and crystal growth hardware has been accomplished by other researchers for early Shuttle flights; however, an extrapolation in specimen size, weight, furnace power and number of processed boules was felt justified to guarantee a high yield, low number of visiting periods and efficient utilization of power. The characteristics of the resulting process are as follows:

Boule	5 cm, dia x 1 meter long
Growth rate	5 cm/hour (continuous)
Power/Furnace	20 kW (continuous)
Number of Furnaces/Factory	15

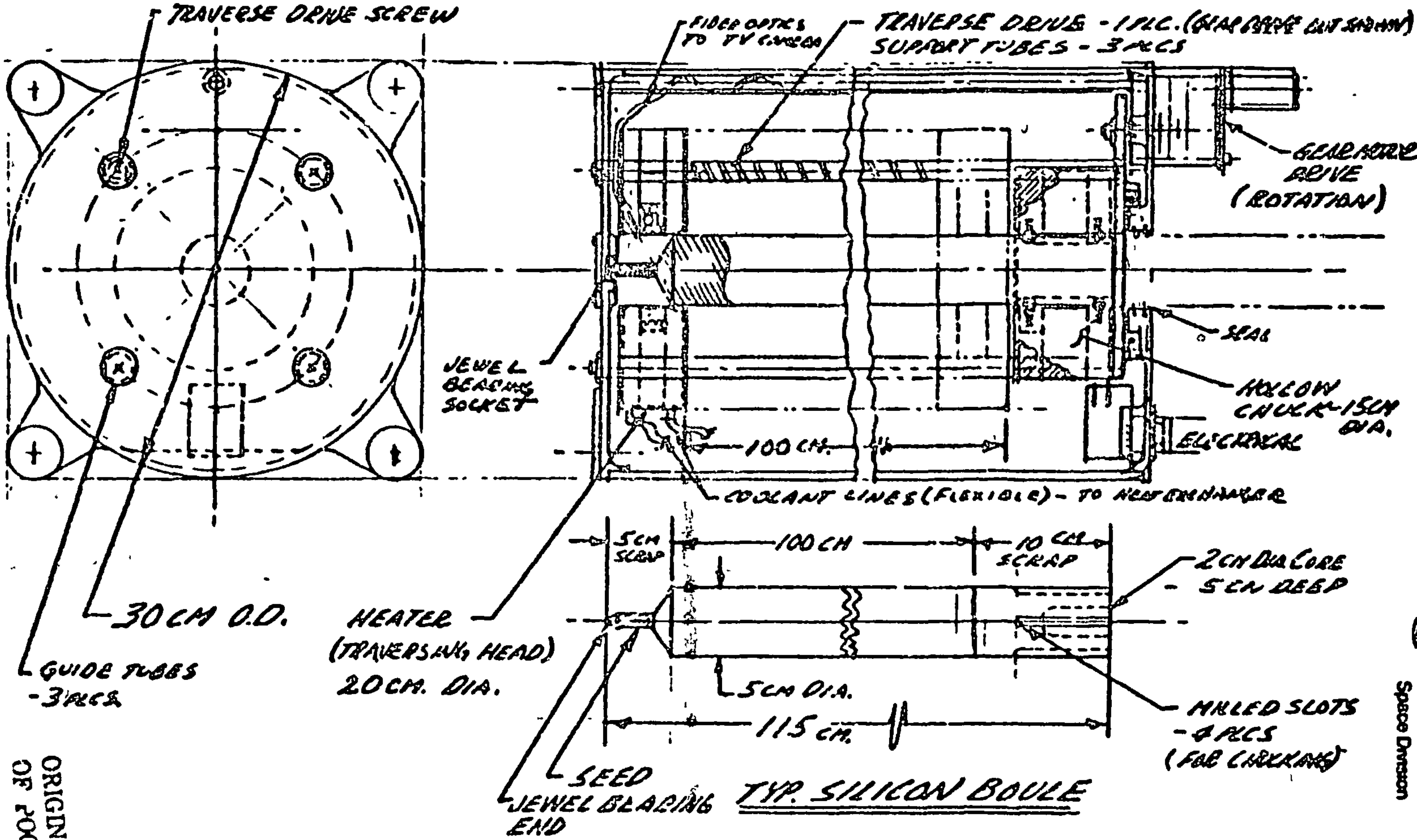
Furnace and Magazine Design

The experimental furnace concept devised by others was retained but sized, as shown in Figure 58, to process the larger boules. The scrap length of the boules was minimized by using a hollow chuck for a rotation drive. The traversing mechanism was designed to process over a 100 cm length of the 115 cm boule. Support of the boule was by the large bearing on the hollow chuck and a conical socket on the other end of the furnace. Each boule requires a seed attached to the 5 cm diameter material and the seed end is ground to act as a jewel-type bearing.

The multiple furnace arrangement, shown in Figure 59, is supported within a 4 meter diameter structure that is connected to a boule magazine that is indexed in 3 degree increments for each product change-out period. The magazine has circumferential storage of boules at radii corresponding to the furnace locations. Total capacity is designed to be 750 boules or 7,772 lbs of raw material.

Shuttle Service and Product Yield

The operation of insertion/retraction of 15 boules may be accomplished in 4 hours time with 20 hours allotted to processing time. This arrangement will yield the following:



Scale: 1 in. = 10 cm.

Figure 58. Zone Refining and Crystal Growth Furnace

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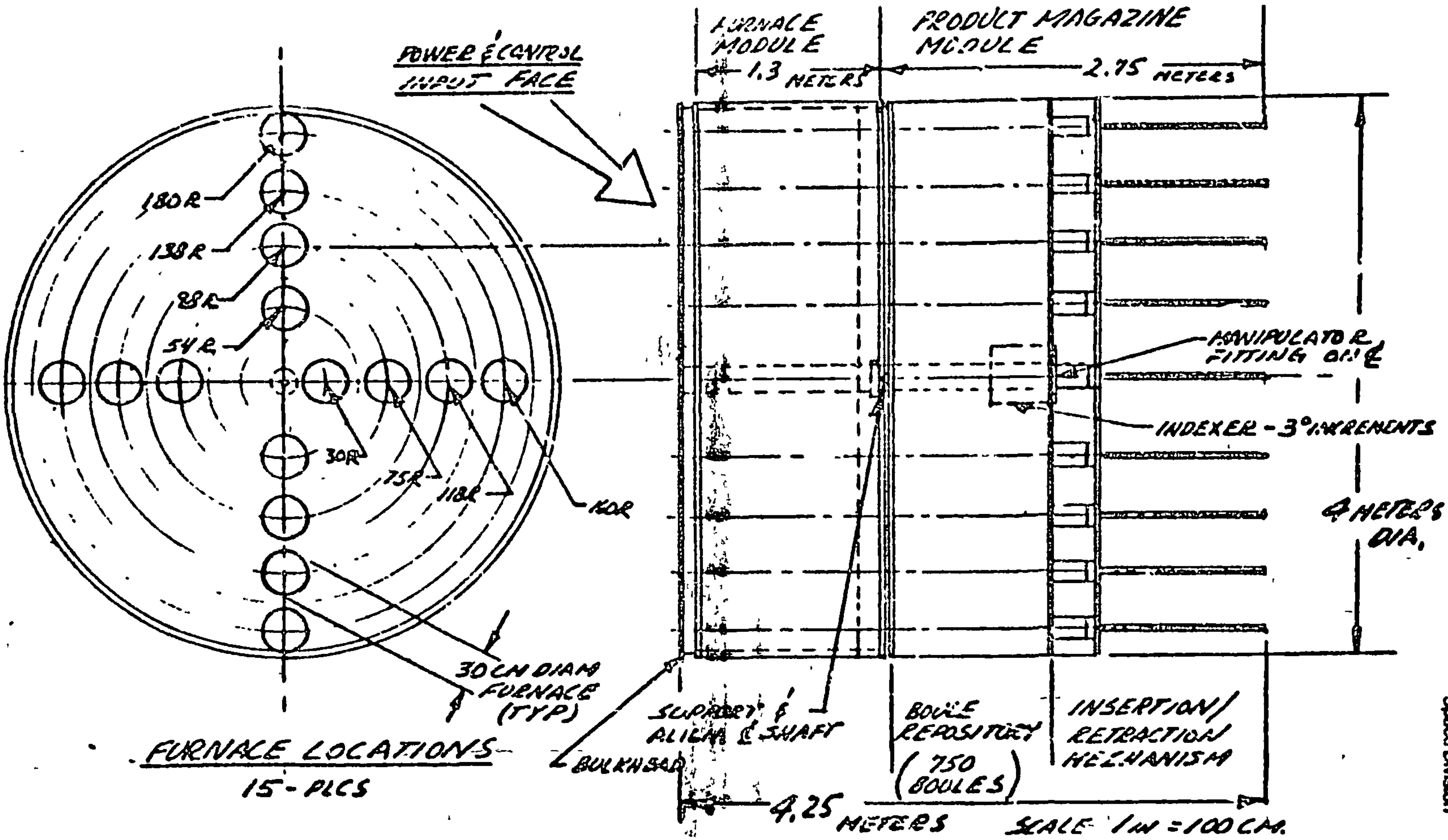


Scale: 1 in. = 100 cm.

Figure 59. Zone Refining and Crystal Growth Module Assembly

1 Day	15 boules
60 Days	750 boules
1 Year	4500 boules
Product Weight/Year	21,150 kg/yr (46,636 lbs/yr)

For a single factory, a total of six service flights would be required, however, if two factories were in operation these same six flights could transport the raw material and finished product in the Shuttle payload bay. Economic operations would probably require about 30 flights per year to service a total of ten factories. This ten-factory complement would yield 211,500 kilograms of finished product per year.

GEOSYNCHRONOUS ORBIT FACILITIES

At last count, more than 70 functioning satellites are hovering above the earth's equator at the geosynchronous altitude. These satellites are devoted almost entirely to high-data-rate communications, and their RF transmissions have already begun to suffer from mutual interference. Certain favorable longitudes, particularly those serving Europe and North America, contain heavy concentrations of powerful transmitters. Moreover, future projections indicate that a population explosion of new satellites is soon to occur in this important spatial region. As the projections in Figure 60 indicate, even under the most pessimistic set of assumptions, the number of satellites in geosync is expected to at least double by [illegible] under more optimistic assumptions, the satellite population could increase by a factor of six or more.

The level of difficulty experienced from crosstalk between adjacent satellites is frequency dependent. At 4 to 6 GHz (the frequency band now in most common use), authorities recommend an orbital spacing of 4° to 5° to insure acceptably low levels of mutual interference. Thus, in accordance with the projections at the bottom of Figure 60, serious problems will begin to emerge at several different orbital locations in the early 1980's. At 20 to 30 GHz the interference problem is considerably less severe; a 1° orbital spacing is believed to be entirely tollerable. However, even with this rather tight spacing, the 1980 satellite population will begin to approach the limits in some regions, particularly those due south of the European mainland.

The Geosynchronous Platform

A multifunction communication platform is one realistic technique that could alleviate the problem of orbital crowding to some degree. By performing several different services such an approach could significantly reduce the total number of geosynchronous satellites that would be required to carry out any given list of communication services. Moreover, a platform that handled combined services would be more efficient and more economical for several different reasons:

1. The various subsystems on board the platform would profit from the sharing of thermal control, stationkeeping, orientation, electrical power and ground support operations.

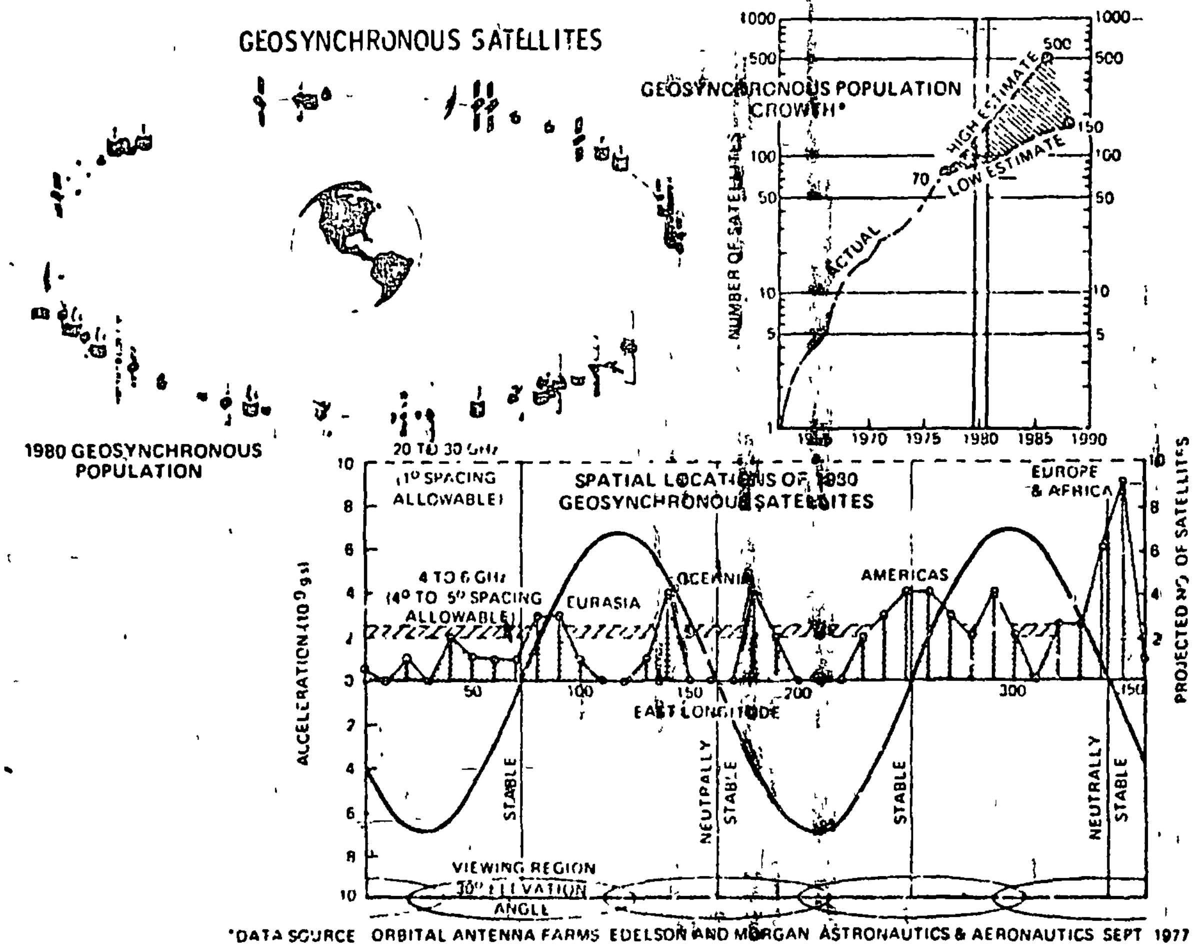


Figure 60. Geosynchronous Orbit Facility Projections

2. Multifunction geosynchronous satellites would benefit from the economies of scale. In particular, a larger spacecraft would have a larger total weight, smaller unit weights, and lower launch costs than would result if each function utilized a dedicated satellite.

3. Increased versatility can be achieved by multifunction design. Specifically, the use of an integrated-satellite design permits interconnecting or *cross strapping* of multiple missions. It also results in fewer costly relay links and much higher quality signals than would otherwise be attained.

Of course, combined missions also give rise to a few bothersome difficulties and these will be discussed in a later section. However, despite these difficulties, it is the opinion of the analysis team that the geosynchronous platform concept offers distinct advantages for the execution of a broad class of missions in an economical way, and that it is an attractive technique for the efficient utilization of the increasingly crowded orbital slots at the geosynchronous altitude.

Platform Description

The geosynchronous platform is sketched in Figure 61. Basically, it consists of a satellite antenna platform, a power distribution and control installation, a 2 degree-of-freedom turntable structure, a solar cell array and a docking ring for Shuttle servicing and on-orbit assembly.

The 500 kW array is constructed of nine beams of 178 meter length. These beams have connecting structures every twenty meters. The solar cell blankets and reflector sides are installed in the three longitudinal gutters of the structure. Gallium aluminum arsenide solar cells are utilized with a concentration ratio of 2:1. The assumed collector efficiency is 18 percent, with a blanket thickness of 4 mils.

A 16 meter diameter turntable is assembled to one end of the solar array. The interior of the first bay of the solar array contains an installation of electrical dc-to-ac inverter machinery. The ac power is distributed into an antenna support platform through two large pivot bearings. Distribution of power is then controlled to each particular transmitter.

Ancillary equipment includes radiators, RCS modules, water and gas storage tanks, communications and momentum storage provided by the rotating electrical conversion equipment. The crosslinks that relay data between duplicate geosynchronous platforms utilize low intensity laser beams.

The total length of the platform is 239 meters and the operational weight is approximated at 29,310 kg (64,629 lbs).

The Services

The geosynchronous platform is designed to perform five separate nationwide services, as described in the following subsections.

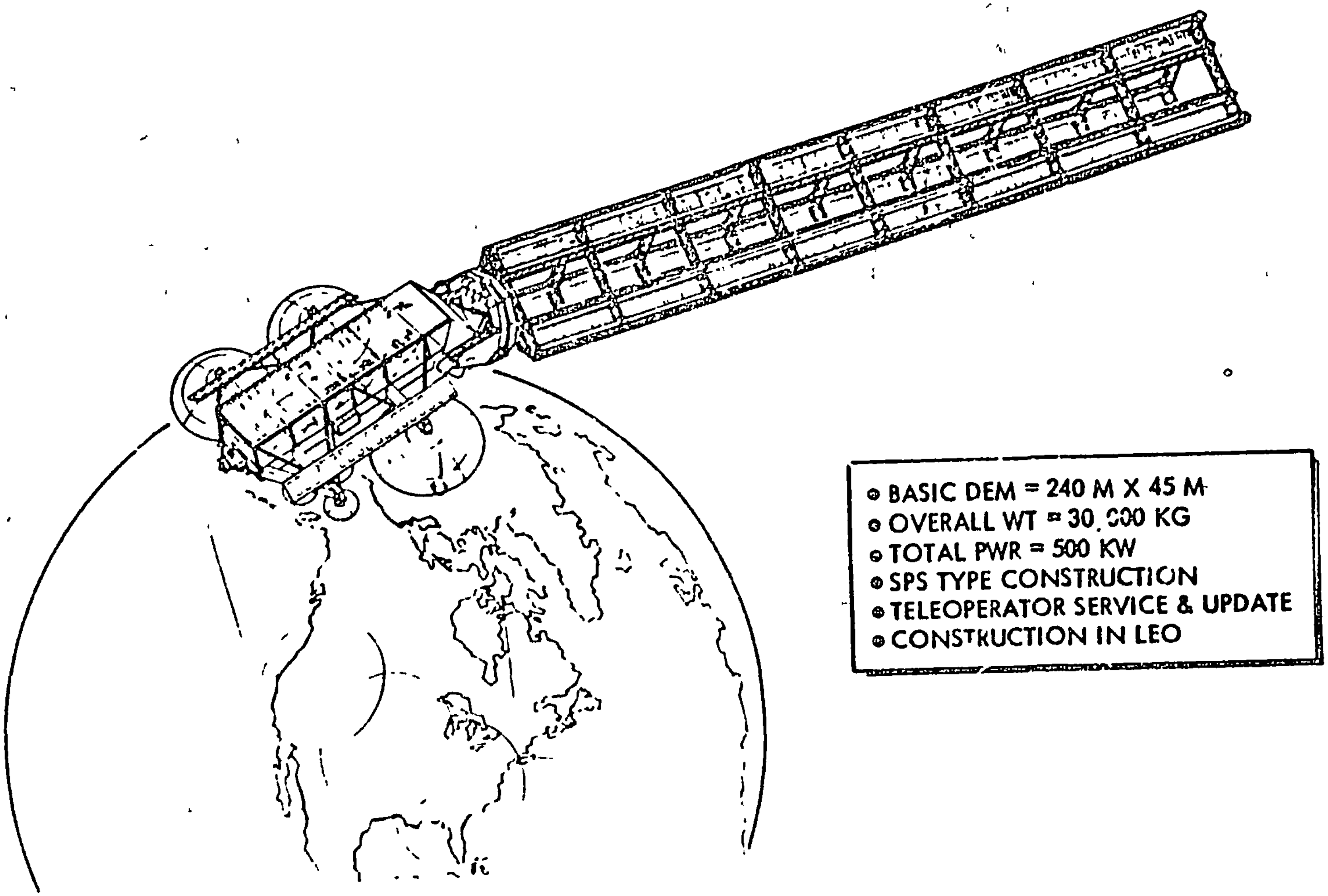


Figure 61. 500 kW Geosynchronous Platform

Broadcast Education

Provisions for five simultaneous color video channels are included with broadcasts taking place 16 hours per day. The primary purpose of the domestic version of this system (see Figure 62) is to provide educational courses for groups that are too dispersed for servicing by existing techniques. For example, a fairly large fraction of the programming will be devoted to captioned and sign language broadcasts to help the 14 million deaf Americans gain new connections within our society and, in particular, our educational system. In-service education for school teachers, specialized training seminars for small business men, job training for unemployed teenagers, and many other types of courses of instruction will also be provided.

As shown in Figure 63, each user will have to purchase a meter rooftop antenna and a small black-box adapter. When produced in mass production quantities, the total cost of these items is expected to be about $100.

The same space hardware can also perform important services for the less developed countries in the world. However, the program materials to be transmitted will be completely different. In general, the purpose of the programs to be broadcast in these areas will be to help the local residents develop marketable skills and to aid them in participating in the local economy. The equipment envisioned for these uses will be self-contained, rugged and extremely simple. As the estimates in Figure show, black and white receivers, complete with antenna and adapter, are expected to be available for about $150 each. Similarly equipped color receivers that retail for $500 should also be possible.

Pocket Telephones

The geosynchronous platform is designed to provide pocket telephone services for 45,000 simultaneous users. If a five percent peak usage rate is assumed, this would mean that 900,000 communicators could be sold before the system would begin to reach saturation. In addition to routine and emergency communications, the pocket telephones will also be used in a national information system. The purpose of this system is to allow ordinary users to have instantaneous access to the useful information maintained within the Library of Congress, the stock market services and other large data systems.

Three-watt hand-held transmitters, equipped with 7 centimeter whip antennas, will transmit to a 18 meter dish antenna which, in turn, will feed the transmissions into a 6 meter dish for relay to a smaller dish antenna located on the ground. This ground antenna will be linked to the conventional telephone system. One advantage of this approach is that it interlinks the communicator with all the telephones in the existing system. Another is that it allows the complex switching hardware to be located on the ground where maintenance and modifications can be carried out with relative ease.

Electronic Teleconferencing

The electronic teleconferencing system will provide 150 simultaneous 2-way teleconferences between any locations in the North American continent. Such a system will promote the efficient exchange of information while cutting fuel consumption, reducing pollution, and saving time for America's busy executives.

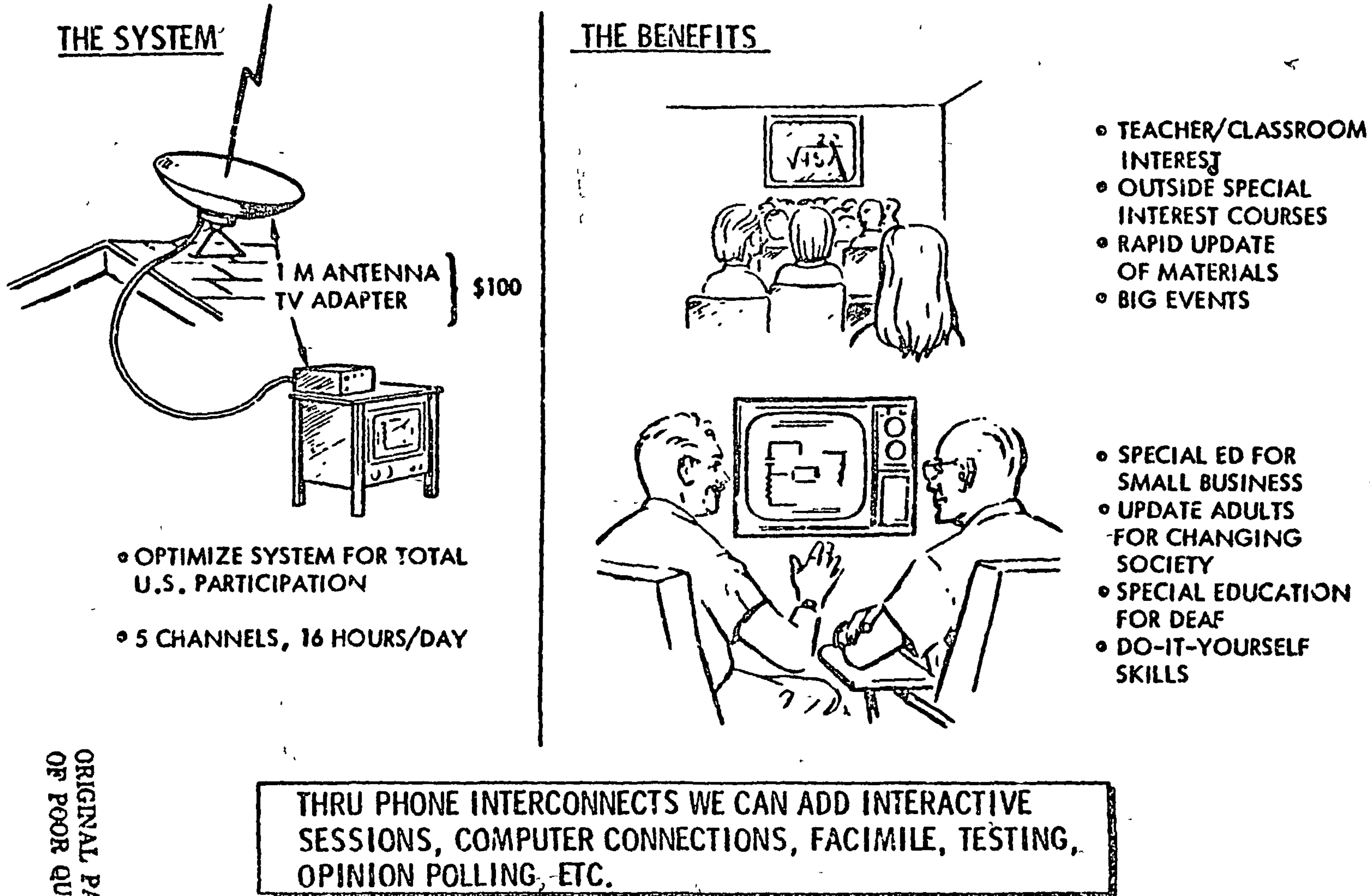
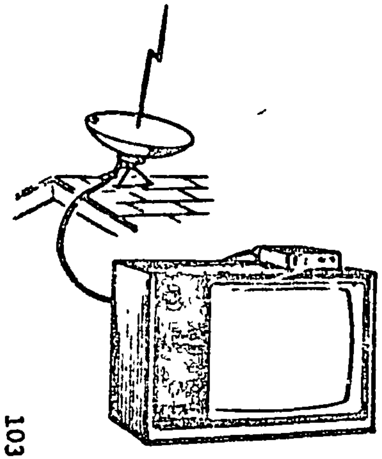


Figure 62. Direct Broadcast Education — U.S.

THE SYSTEM



ANTENNA PLUS
SPECIAL B&W
TV SET $150
OR
LARGE COLOR SET
WITH POWER SUPPLY
FOR $500.

- GROUND SETS MADE DURABLE INEXPENSIVE, AND EASY TO USE
- SETS SOLD IN SMALL COUNTRIES PICKS UP ONLY THE APPROVED PROGRAMS.
- TAILOR THE COURSES TO LOCAL SITUATIONS - EDUCATIONAL LEVEL, LOCAL JOBS, SPECIAL NEEDS

THE BENEFITS

- TOTAL COUNTRY COVERED
- CAN LEARN LOCALLY USEFUL SKILL EVEN IF ILLITERATE
- NO PIPELINE OF BOOKS, ETC. REQUIRED
- INSTANTLY UPDATEABLE
- WIDE VARIETY OF PROGRAMMING - HEALTH CARE, BIRTH CONTROL, BASIC EDUCATION, SPECIAL SKILLS

WITH HUMAN KNOWLEDGE AND PRODUCTIVITY COMES A BETTER LIFE PLUS BUYING POWER FOR HIGH-TECHNOLOGY PRODUCTS

Figure 63. Direct Broadcast Education — LDC's

An experimental version of the proposed system, called *Project Prelude*, was recently set up at three large American corporations (Rockwell International, Texaco, and Montgomery Ward). As Figure 64 shows, the 200-watt CTS satellite was used in these experiments to transmit color TV images (including 0.5 second freeze-frames), rapidfax and direct high-speed computer data throughout the course of this experimental series.

Electronic Mail

The fourth service of the geosynchronous platform is electronic mail. The system is set up to handle 40 million pages of mail with overnight delivery from 800 sorting centers. Substantial improvements in service may eventually result from this technique. It also seems likely that productivity gains will result from the fact that the mail can be sorted electronically and it will arrive at its destination in a timely and reliable manner.

The Antennas

The geosynchronous platform uses a total of 30 antennas of various sizes in order to perform all five of the required services. The sketches in Figure 65 show the relative positions of these antennas with shading to indicate whether they receive data, transmit data or operate in a diplex mode. The largest antennas which are devoted to personal communications are 18.3 meters in diameter; the smallest which handle electronic teleconferencing have a diameter of 1 meter.

The power requirements for the various services are also tabulated in Figure 65. The total power is 454.4 kw. In addition to the values in the tabulations, a 10 percent contingency is allowed, thus a total of 500 kilowatts is actually provided.

The spot beam patterns, transmission bandwidths, and the necessary power levels for the various services are shown schematically in Figures 66 through 69. Also shown in these diagrams are the sizes, types and numbers of antennas and the transmission paths.

Technical Considerations

A conceptual design of an early integrated geosynchronous platform is shown in Figure 61. In consultation with Science Applications, Inc. (SAI), five nationwide information services were selected, and the system parameters defined. These are:

1. Direct Broadcast Television - Multiple channels to be received on a modified conventional TV receiver. The entire CONUS area is to be covered (excluding Alaska, Hawaii, and Puerto Rico). Programming would originate from a single ground installation, but may be developed by any agency.

2. Pocket Telephones - Multiple voice channels originating from remote, wireless extensions; to be connected to conventional fixed terminals, or other remote terminals via satellite. Saturation capacity to be at least 45,000 simultaneous transpactions.

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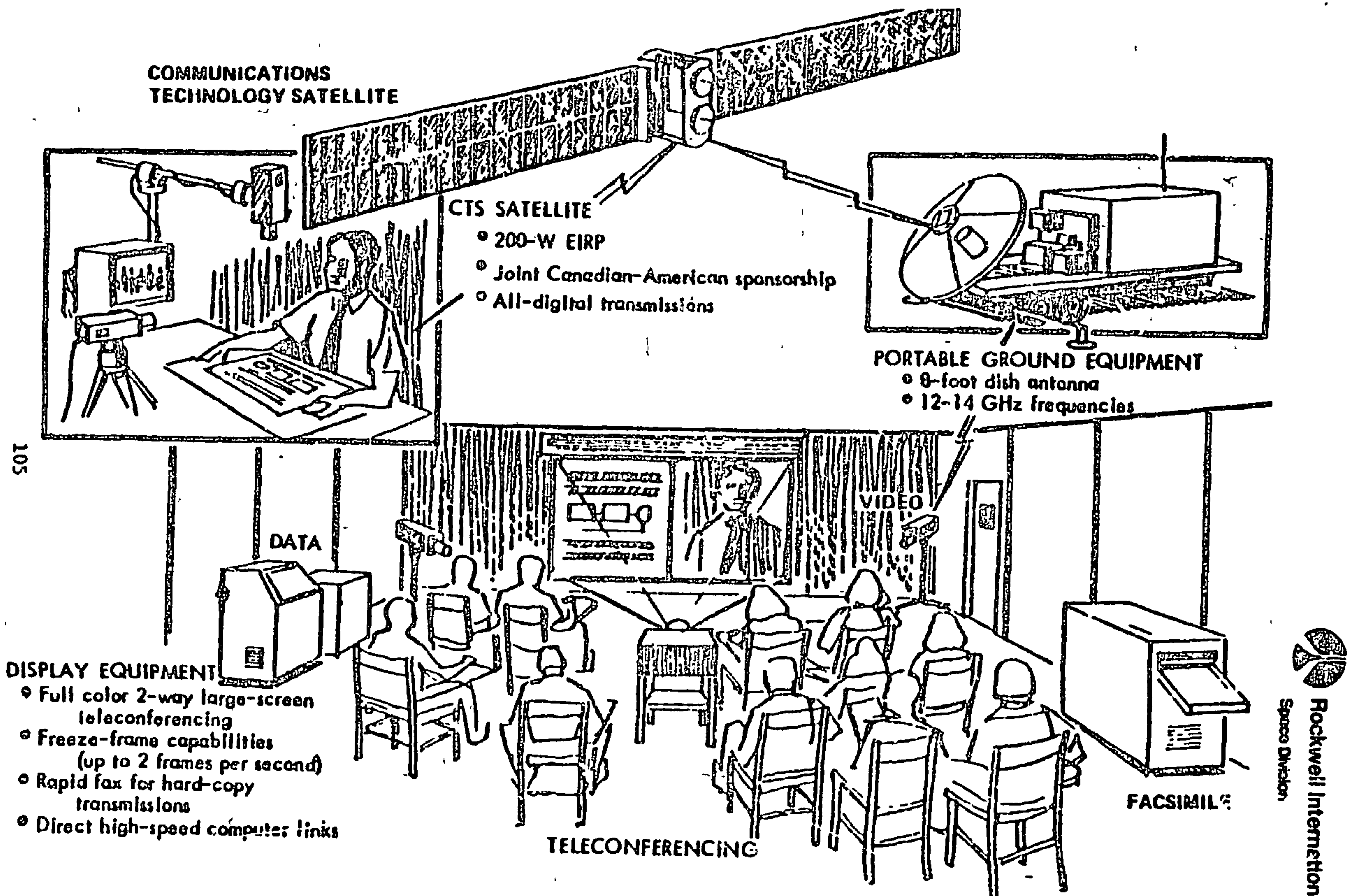

Figure 64. Video and High Data Rate Communications Demonstration

POWER REQUIREMENT

SERVICE	POWER (KILOWATTS)
DIRECT BROADCAST T V	270
POCKET TELEPHONES	127 4
NATIONAL INFORMATION-SERVICES	INCLUDED WITHIN PERSONAL COMMUNICATIONS
ELECTRONIC TELECONFERENCING	34
ELECTRONIC MAIL	13
ELECTRONICS	10
TOTAL	454 4

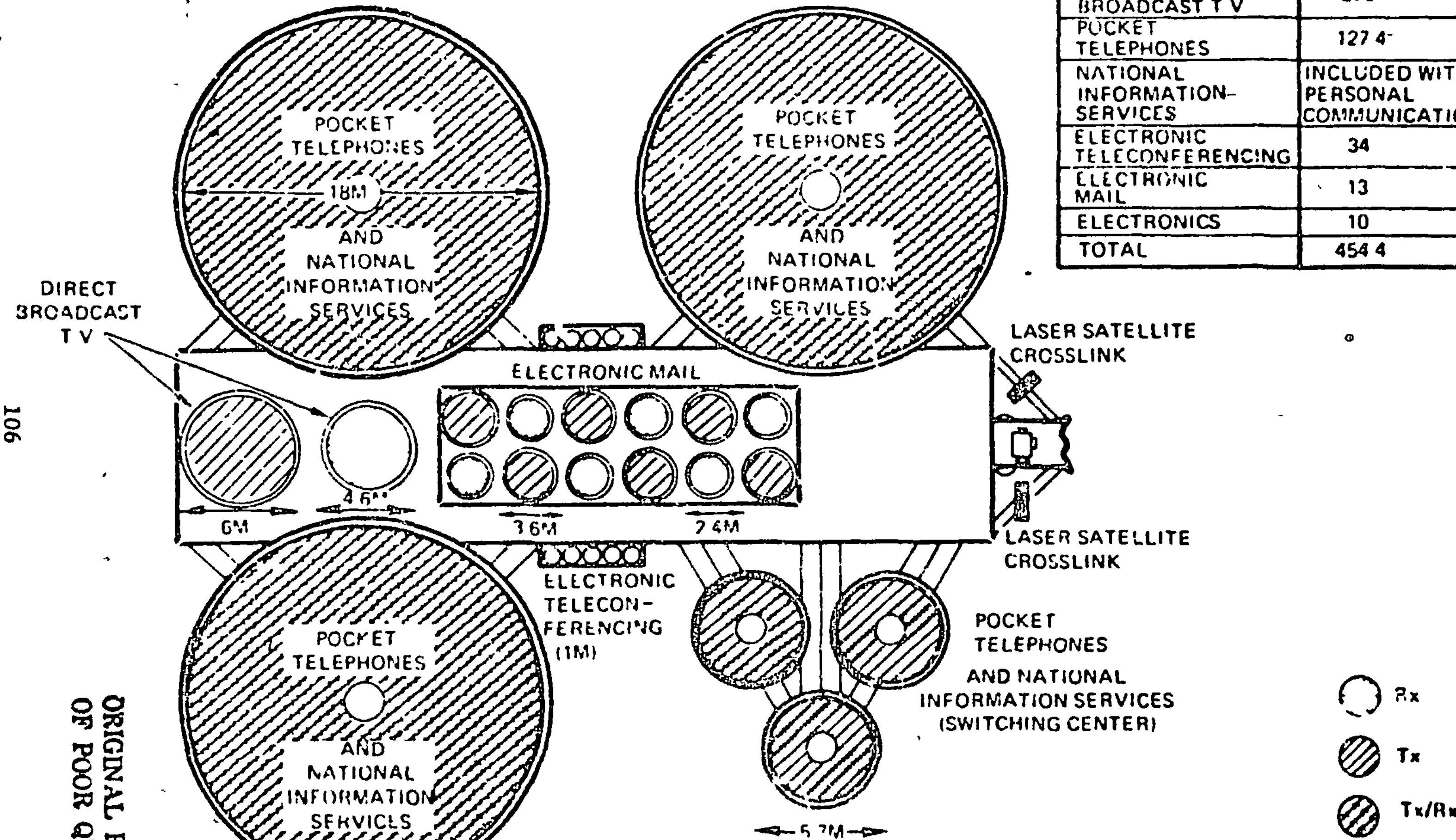

Figure 65. Antenna Locations for the Geosynchronous Platform

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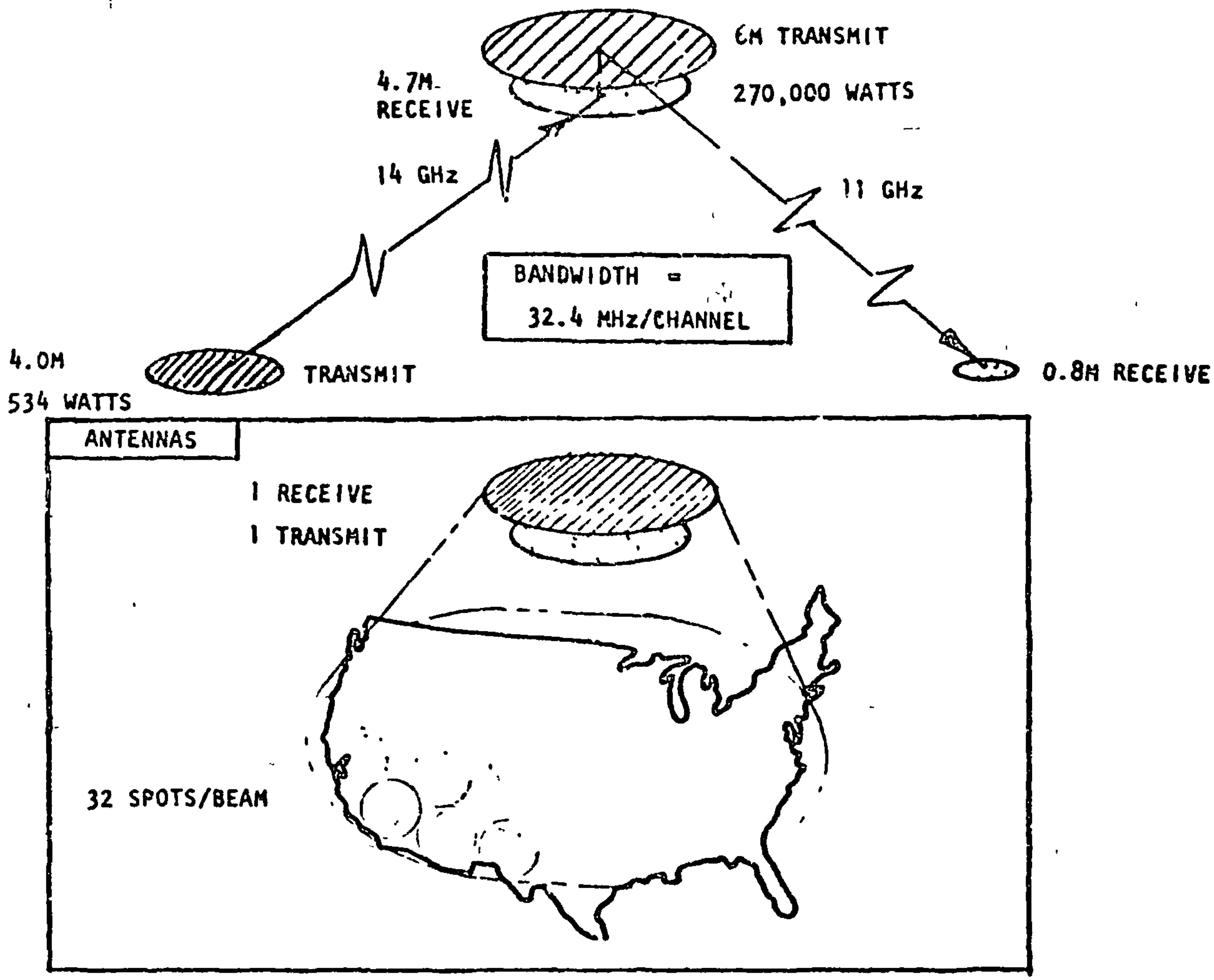

Figure 66. Broadcast Education

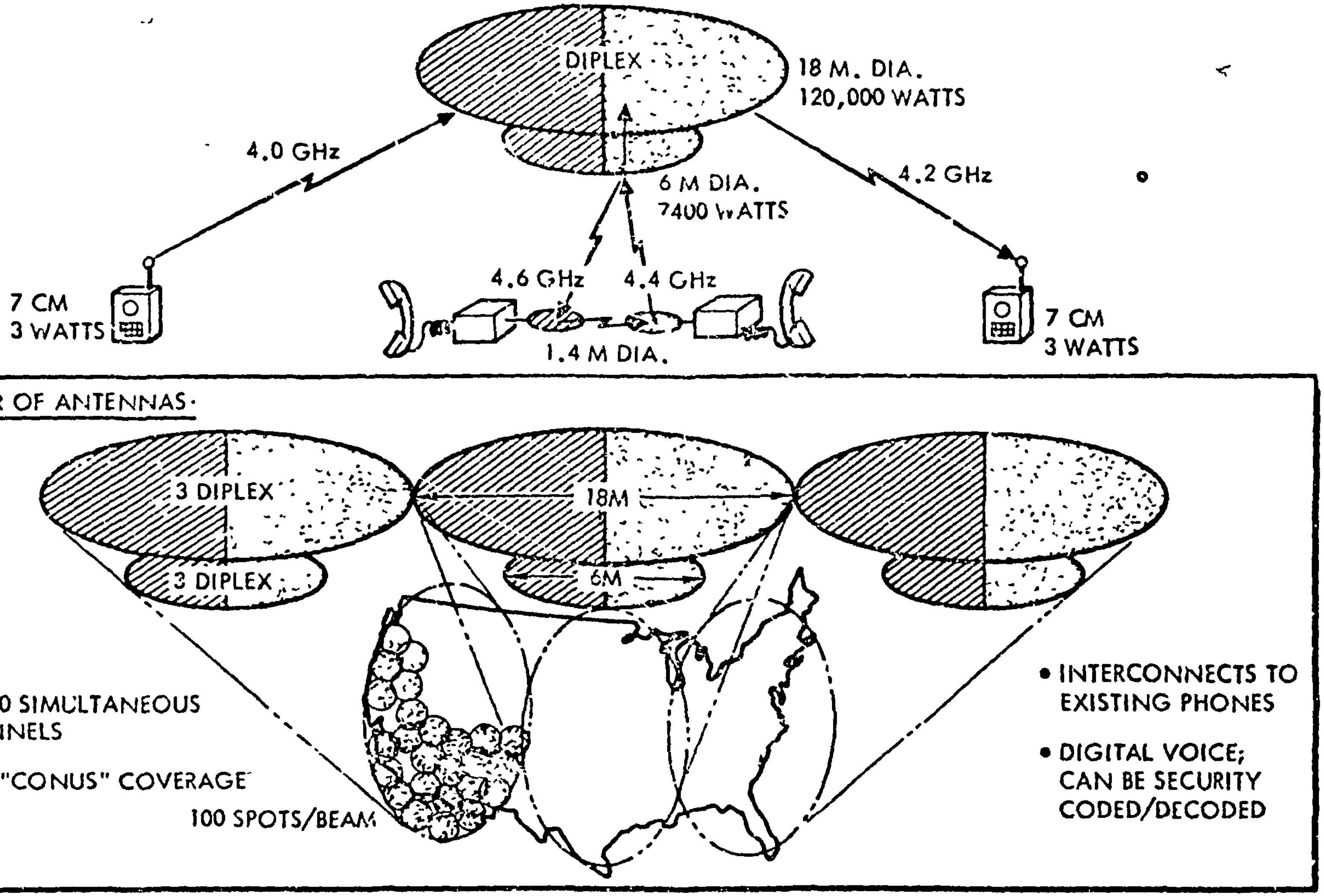

Figure 67. Pocket Telephones (and National Information Services)

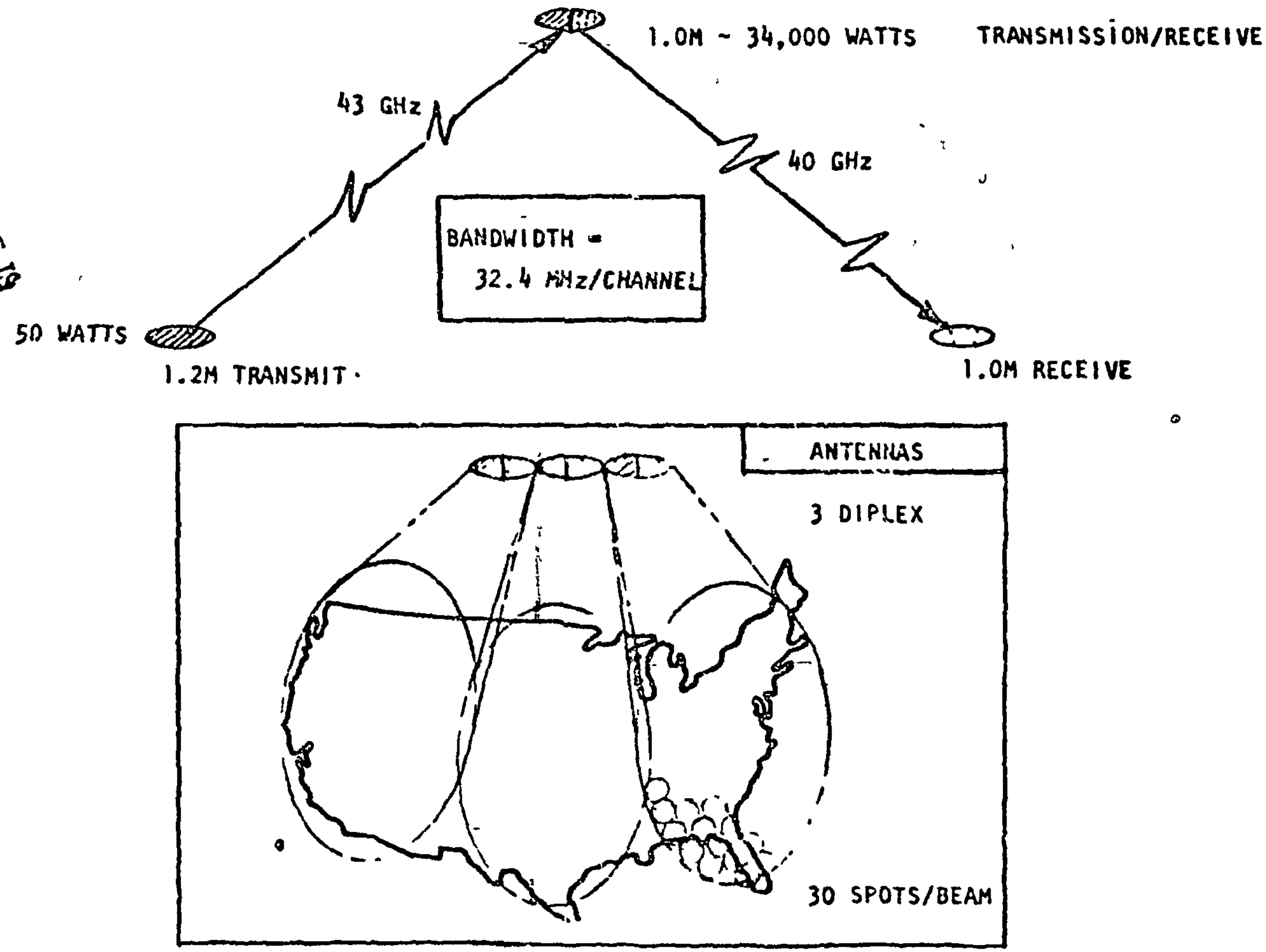

Figure 68. Electronic Teleconferencing

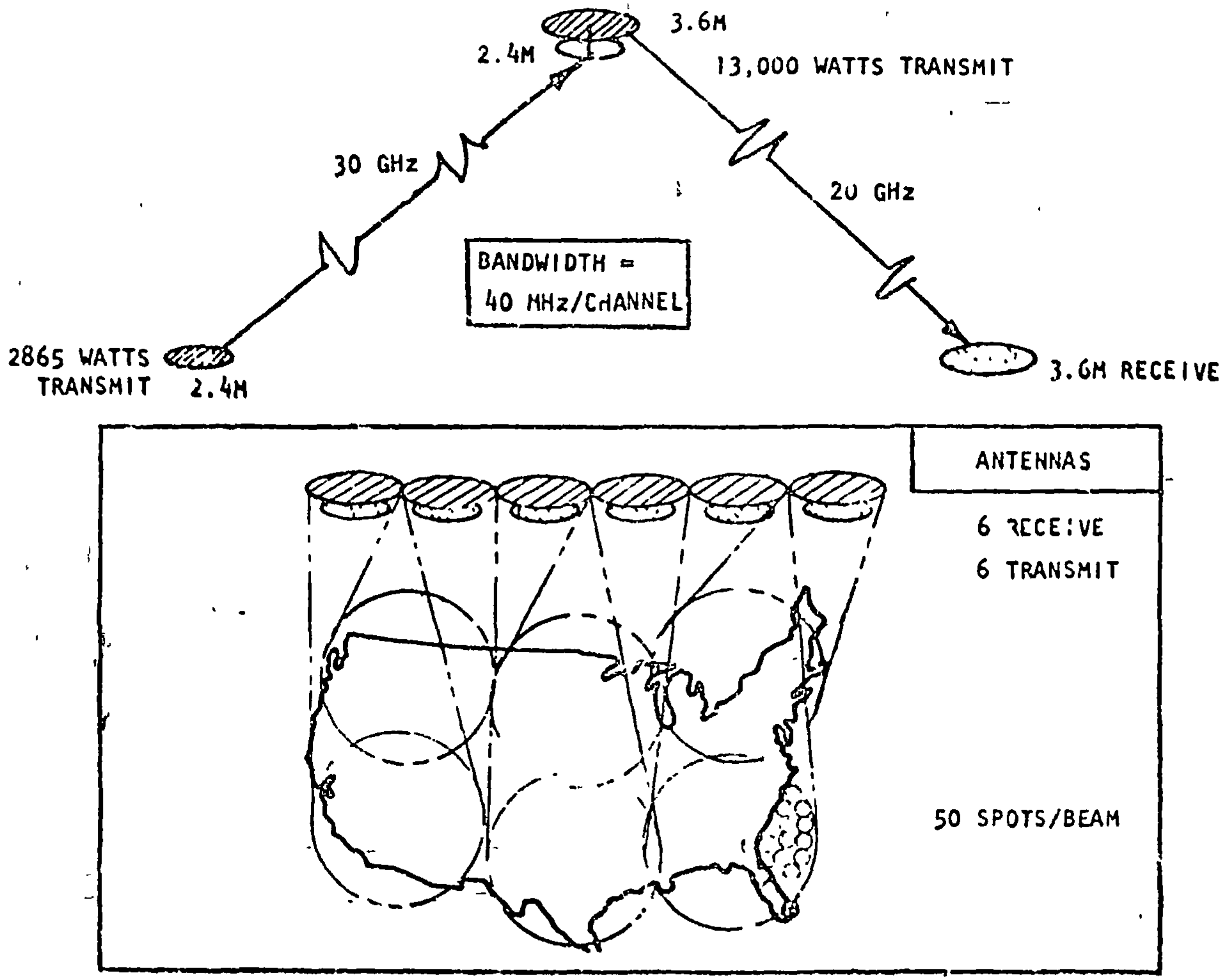

Figure 69. Electronic Mail

3. National Information Services - Direct access via satellite from home or business *intelligent terminals* to computer-supported data banks, such as the Library of Congress. Capacity requirements are not specified.

4. Teleconferencing - Two-way (or multiple) video links between isolated ground sites. User locations would have studio-type facilities, including multiple cameras and monitors, switch gear, and communications. Capacity requirement was not specified.

5. Electronic Mail - Facsimile transmission of personal and business correspondence. Terminals would be local Post Offices, linked to a regional *sorting center* by cables or similar ground links. Sorting centers are interconnected via satellite, the number to be at least 800. The local Post Office would provide equipment to convert hard copy to electronic facsimile, and vice versa. Goal is to deliver 40 million pages (8-1/2 x 11) from source to destination over night.

The conceptual design shown in Figure 70 (Dwg. 78255-001) was approached from three directions: to select appropriate communications parameters (frequency allocation, modulation bandwidth, antenna gain/directivity, total power required); to select an appropriate spacecraft configuration (power generation, pointing and stabilization, assembly methodology); to define the ground *user* terminals.

Two crucial constraints were assumed:

1. The total prime power generated should not exceed 500 kW per installation; this was felt to be the limit of large space structures technology in 1987 — and it assumes that SPS development requirements dictate the specific approach.

2. Frequencies must be in accordance with those allocated by international agreement for this type of service.

A further guideline was assumed: that the system should be designed and the frequencies allocated so that the user terminal cost is inversely proportional to the number sold. Therefore, for services like personal communications, the remote *telephone* should be simple and inexpensive, placing the burden of performance on the satellite. Conversely, for electronic mail there would be relatively few terminals in the local Post Offices and, hence it can be more complex and expensive.

Following a sequence of rather complicated *trade-off* trials, the satellite communications requirements were defined as follows:

Spacecraft Power Budget	Prime Power
Broadcase TV (5 Channels)	270 kW
Personal Communications (45,000 Users)	127.4 kW
National Information	-

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Teleconferencing (150 Channels)	34	kW
Electronic Mail	13	kW
Spacecraft (assumed)	10	kW
Total Prime Power	454.4	kW

Direct Broadcast Education

Uplink	14	GHz
Downlink	11	GHz
Ground Transmit Antenna	4.0	Met
User Recieve Antenna	0.8	Met (2° Beamwidth)
Satellite Receive Antenna	4.7	Met - Need 1
Satellite Transmit Antenna	6	Met - Need 1
Dc Power/Channel	54	kW Times 5 Channels = 270 kW
32 Beams (Transponders) Times 5	160	Transponders, 265 watts RF, each

Pocket Telephones

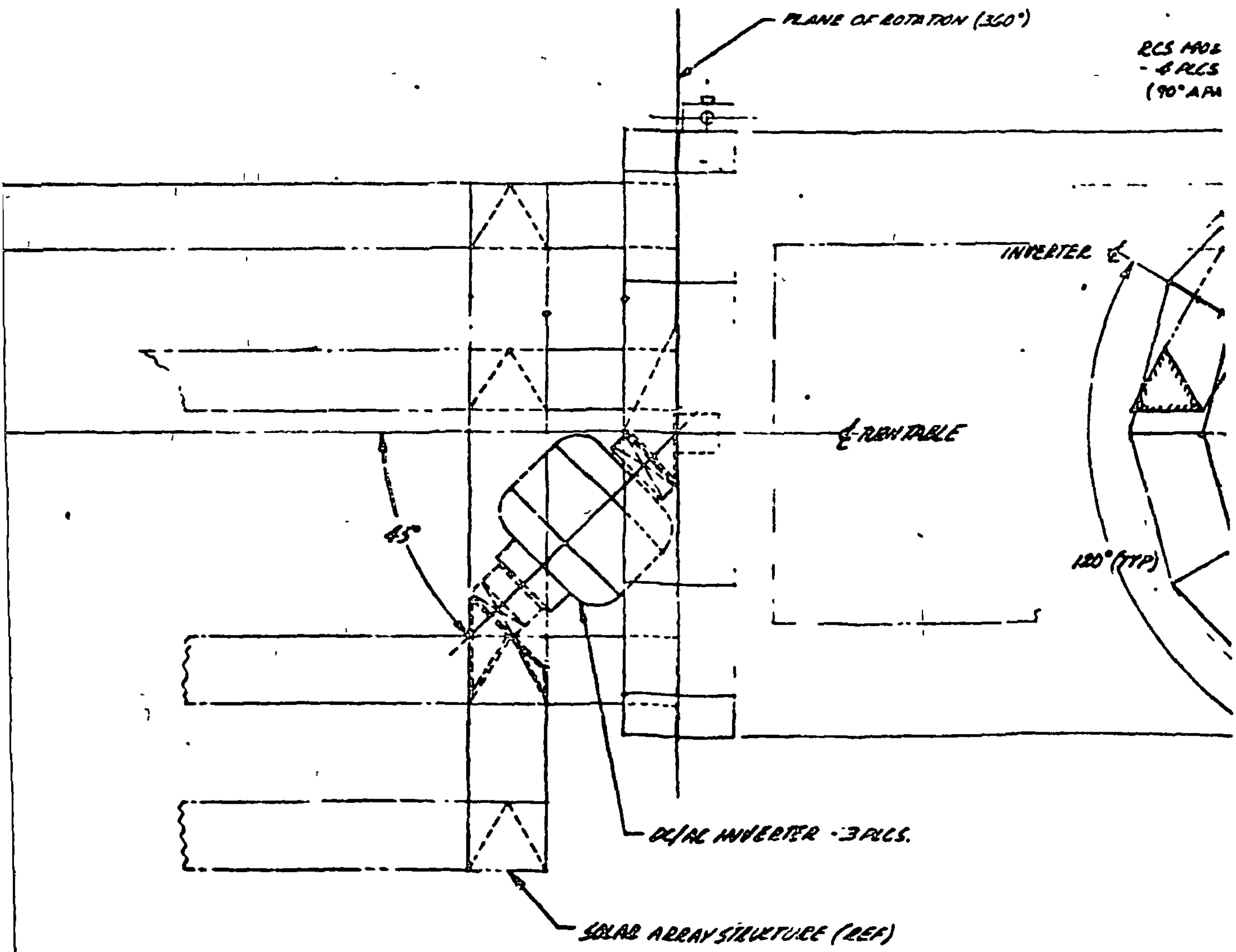
Uplink/Downlink	4.0/4.2	GHz (to the Remote User)
Uplink/Downlink	4.4/4.6	GHz (to the Switching Center)
Ground Antenna, User	7	cm [illegible] (to/from the Satellite)
Dc Power, User	3	watts (approximately)
Dc Power, Satellite to User	127.4	kW
Number of Simultaneous Users	45,000	
S/C Antenna, Transmit -	18	Met - Need 3 (to the User)
-	6	Met - Need 3 (to the Switching Center)

National Information Service

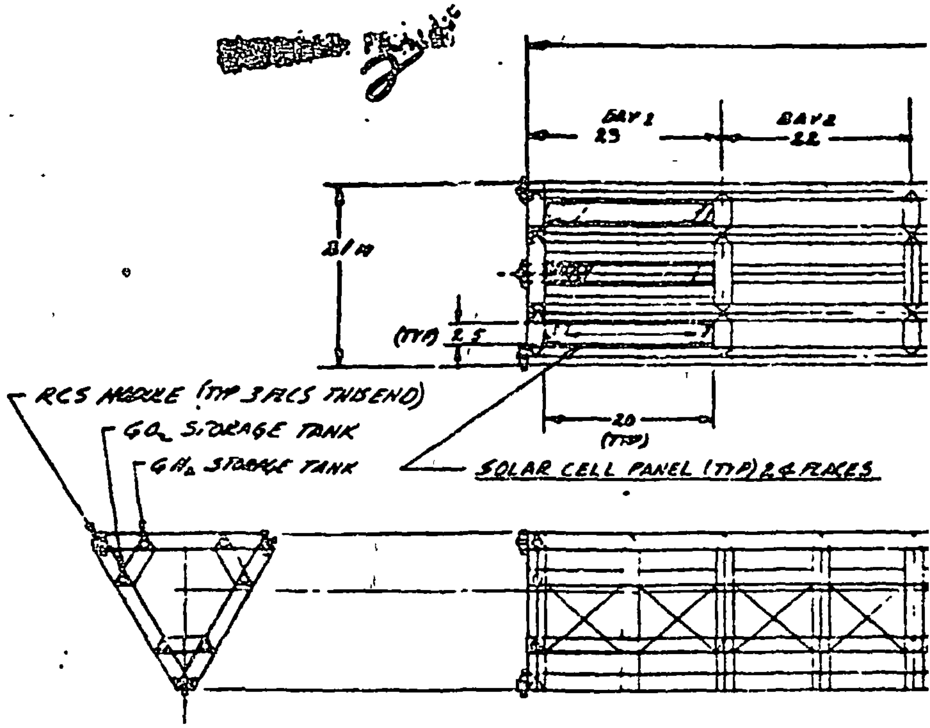
Would use personal communications system except for ground terminal and a larger user antenna.

Teleconference

Uplink	43	GHz
Downlink	40	GHz
Capacity	Up to 150 Pairs'	
Ground Site Antenna (Uplink/Downlink)	1.2/1.0	Met

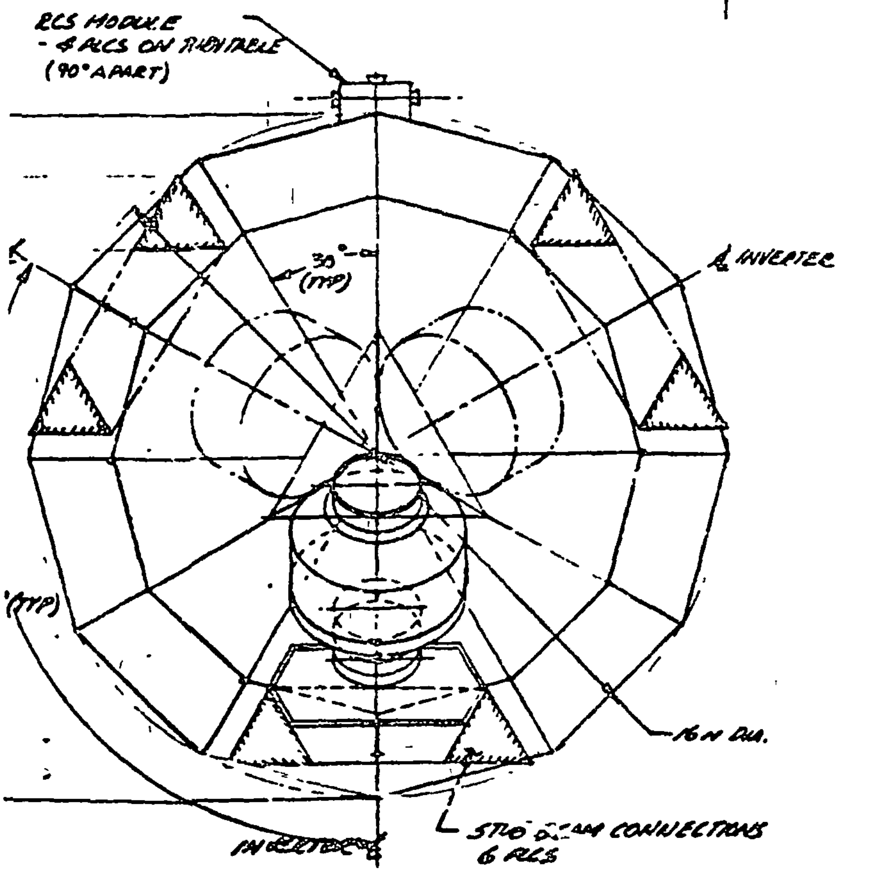

PLANE OF ROTATION (360°)
RCS MOD
- 4 PLCS
(90° APA
INVERTER ℄
℄ TURNTABLE
45°
120° (TYP)
DC/AC INVERTER - 3 PLCS.
SOLAR ARRAY STRUCTURE (REF)

	14	13	1:



REFLECTOR SURFACES (TYP)

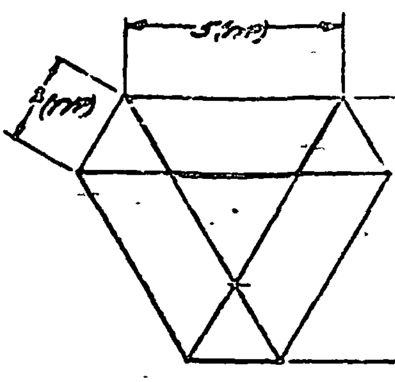
SOLAR CELL & BLANKET INSTAL. (TYP) 3 GUTTERS



TURN TABLE STRUCTURE

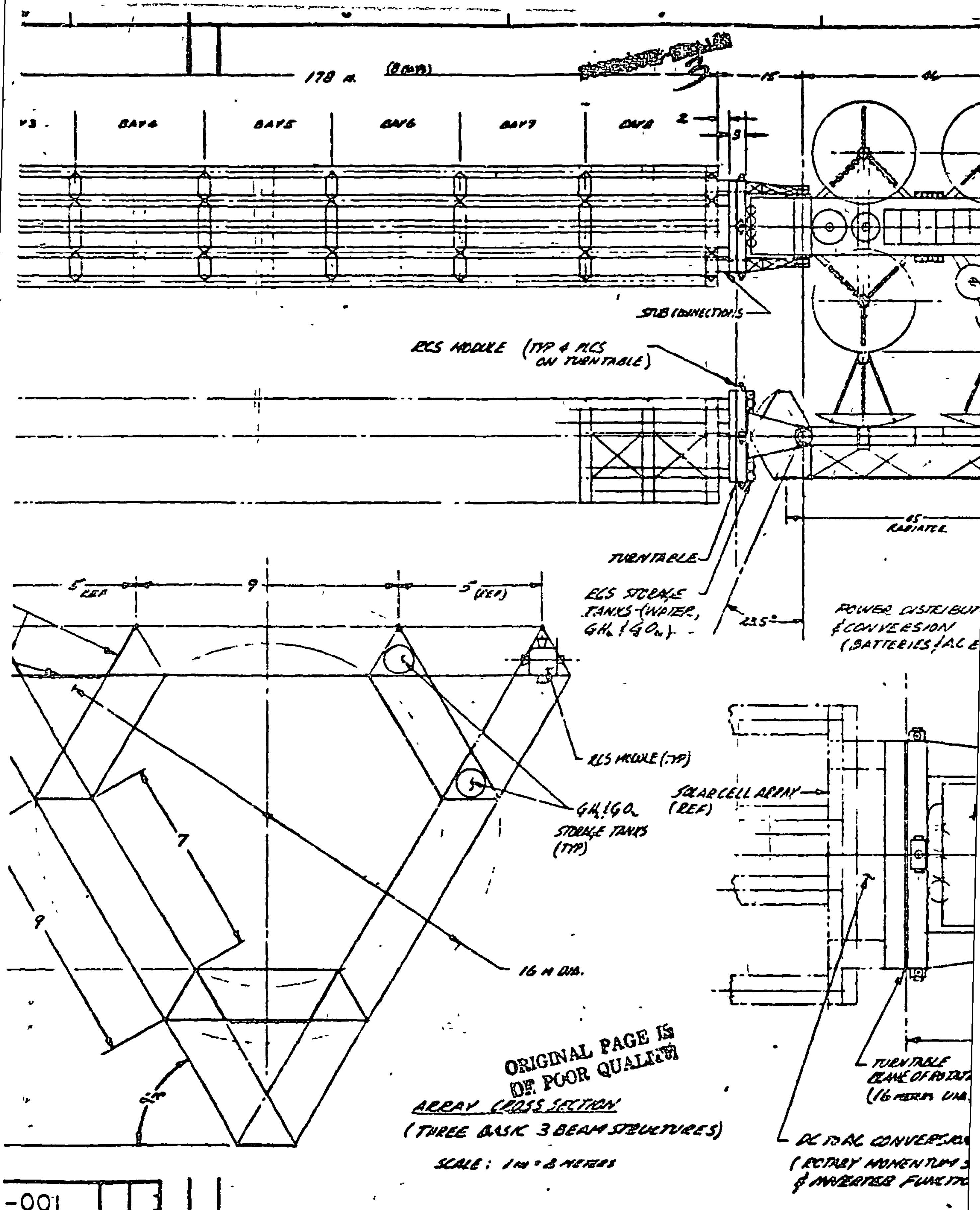
(DC/AC INVERTER SHOWN ONE PLC. FOR CLARITY) - 3 REQ'D

SCALE: 1 IN = 2 METERS



BASIC 3 BEAM STRUCTURE

SCALE: 1 IN = 2 METERS



ARRAY CROSS SECTION
(THREE BASIC 3 BEAM STRUCTURES)

SCALE: 1 IN = 8 METERS

-001

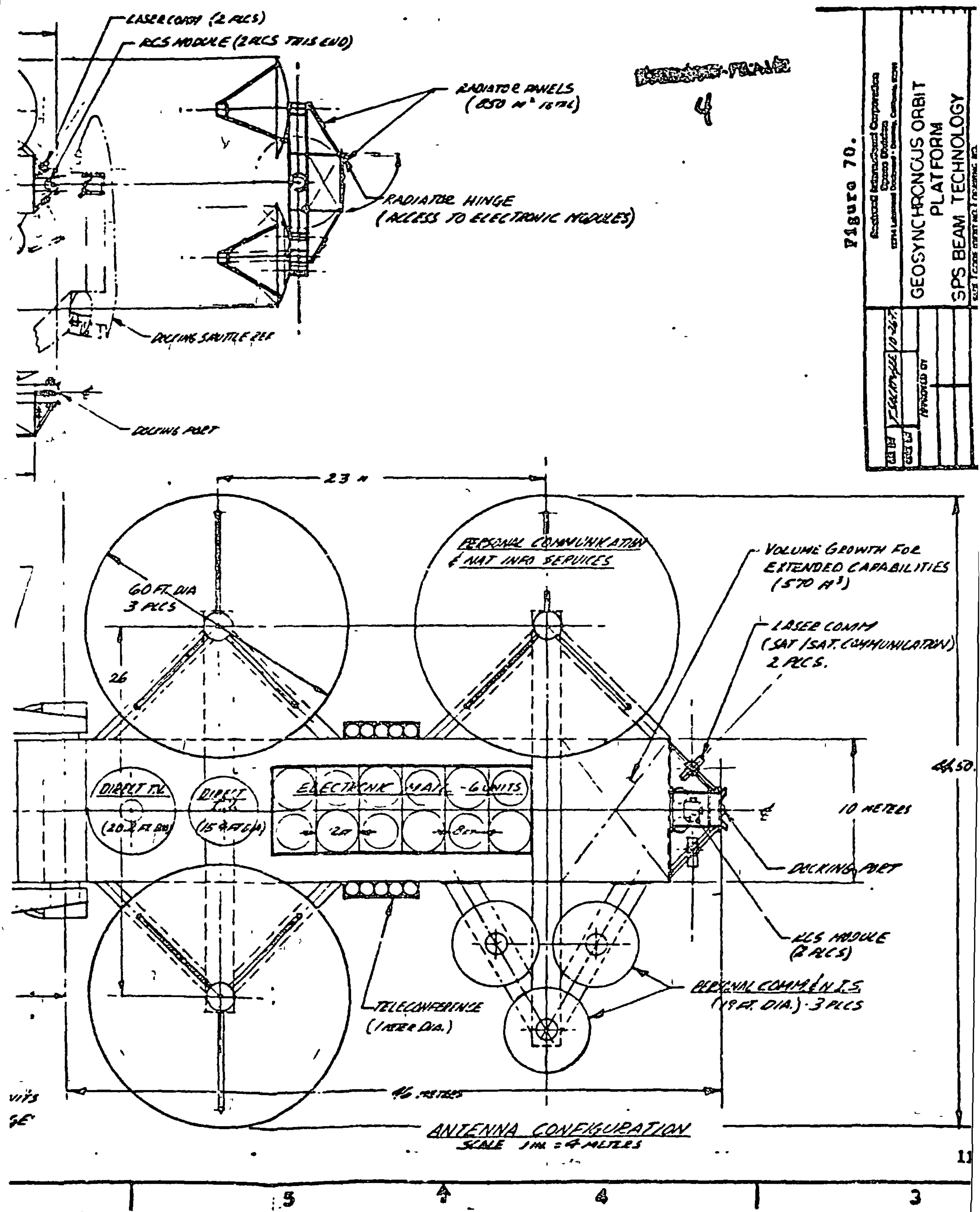

LASER COMM (2 PLCS)
RCS MODULE (2 PLCS THIS END)
RADIATOR PANELS (850 M² TOTAL)
RADIATOR HINGE (ACCESS TO ELECTRONIC MODULES)
DOCKING SHUTTLE REF
DOCKING PORT
23 M
PERSONAL COMMUNICATION & NAT INFO SERVICES
60 FT. DIA 3 PLCS
26
VOLUME GROWTH FOR EXTENDED CAPABILITIES (570 M³)
LASER COMM (SAT/SAT. COMMUNICATION) 2 PLCS.
DIRECT T.V. (20.2 FT DIA)
DIRECT T.V. (15 FT DIA)
ELECTRONIC MAIL - 6 UNITS
10 METERS
DOCKING PORT
RCS MODULE (2 PLCS)
PERSONAL COMM & N.I.S. (19 FT. DIA.) - 3 PLCS
TELECONFERENCE (1 METER DIA.)
46 METERS
ANTENNA CONFIGURATION
SCALE 1 IN. = 4 METERS
GEOSYNCHRONOUS ORBIT PLATFORM
SPS BEAM TECHNOLOGY
5
4
3

Figure 70.

Satellite Antenna	1.0	Met - Need 3
DC Power	Approximately 55 w/Channel	
Total for 80 Channels	34	kW

<u>Electronic Mail</u>

Uplink	30	GHz
Downlink	20	GHz
Satellite Antenna (Transmit)	3.6	Met, 0.28° BW - Need 6
Satellite Antenna (Receive)	2.4	Met, 0.28° BW - Need 6
Ground Antenna (Receive)	3.6	Met
Ground Antenna (Transmit)	2.4	Met
Satellite RF Power/Beam	14.5	watts
Number of Beams for Conus	300	
Total DC Power	13	kW
Average Transmit Rate	1.0	mbps, for 4 hours per day, 250 days per year

Considering the defined communications parameters, a preliminary space element concept was developed. The two major elements are the power generation system and the platform system. These are described below.

Power Generation Subsystem

The power generation subsystem consists of four assemblies: (1) solar power assembly, (2) DC/AC conversion assembly, (3) distribution assembly, and (4) sun orientation assembly.

The power generation subsystem will provide a minimum of 500 kW of usable power to the spacecraft and payload systems as 115/230 vac, at ±0.5 percent voltage regulation. Frequency shall be approximately 4000 Hz. The power allocations are:

Spacecraft	10	kW
Broadcast TV	270	kW
Pocket Telephones	127.4	kW
National Information Services	-	
Electronic Telconferencing	34	kW
Electronic Mail	13	kW
Margin	45	kW
Total	500	kW

During operation, power shall be allocated on a *demand* basis. The expected demand is:

Spacecraft	Continuous
Broadcast TV	16 hrs/day, 365 days/year
Pocket Telephones	Continuous
National Information Services	8 hrs/day, working days only
Electronic Teleconferencing	8 hrs/day, working days only
Electronic Mail	4 hrs/day, working days only

Solar Power Assembly. The solar power assembly is derived from the work done by Rockwell for the Solar Power Satellite (SPS), assuming the technology, assembly methodology, and hardware derivatives developed for the SPS will be available for use in the desired time frame. Thus, the solar power assembly is a rectangular, triangle structure supporting three identical *solar blanket* gutters. It shall be assembled in a low altitude orbit by fabricating *beams* (using the SPS Beam Forming Machine) from Shuttle-supplied materials. On one face of each triangular beam is installed a reflective trough in which are laid prefabricated solar *blankets*. As each beam is constructed, crossties will be added.

After primary structure assembly, interconnecting cabling, coarse (shunt) regulation elements, and thermal control elements are added. Three dc/ac converters are installed at one end, as is the payload mounting ring.

The total solar power assembly will be oriented with the solar blankets normal to the sun, ±3 degrees. The vehicle is at geosynchronous altitude, in the equatorial plane, at longitude 96° W. The long axis of the solar power assembly is normal to the orbital plane; thus, it must *nod* ±23-1/2 degrees in the meridian plane (yearly cycle) to remain oriented towards the sun. It must also rotate once per day on the axis in the orbital plane.

The solar power array consists of two main structures:

1. Solar cell-beam structure
2. Turntable-power conversion structure

Space assembly is initiated by construction of the turntable. This structure consists of 12 segments of ground manufactured box beams that are bolted together in space to form a 12-sided ring structure of a maximum diameter of 16 meters. On this structure two tapered beams are placed to locate the antenna platform pivots. Supporting structure and the dc-to-ac conversion equipment are mounted to the array side of the turntable. The electrical conversion equipment is then spun-up to give the entire structure inertial stability in orbit for the attachment of other main structural elements.

The second major assembly in orbit is the manufacture of single beams by a *beam machine* and the concurrent attachment of special shaped beams to finally arrive at a large triangular cross section containing nine longitudinal beams.

The solar array structure is aligned by tension wires and attached as a unit to the stub-beams of the previously assembled turntable. After this operation, the Shuttle remote maneuvering system is employed to emplace and fasten the solar cell/blanket rolls in the three gutters, as indicated. Electrical distribution wiring, electrical control hardware and system connections are made prior to the final close-out operation of draping the side reflectors on each of the three gutters.

Reaction control modules and reactant tankage are then applied to the free end and the turntable structure. RCS propellant storage tanks remain to be applied to the turntable prior to an on-orbit checkout. The antenna platform description and assembly may be found in the Platform System section.

DC/AC Converter Assembly. Each of the three identical panels will generate up to 167 kW; since it is a long (500 plus feet) panel, care must be taken to avoid excessive internal losses (I^2 R) by implementing a high-voltage, low current design. Practice indicates that a nominal dc potential of about 2800 vdc is feasible without excessive penalty of insulation or danger of coronal discharge. Thus, the nominal current would be 60 amperes.

It is necessary to transfer most of this power across a rotating joint to the payload. It is also desirable that the power delivered to the point of use (the payloads) be in the form of low-voltage ac. Due to the power level, it is not presently justifiable to assume a solid-state inverter, therefore, a mechanical rotating device was selected to perform the required electrical functions/conversion function.

Such a mechanical converter, even at 4000 Hz, represents a significant mass of iron, and an even more significant inertial momentum. To avoid providing compensating momentum, the three rotating inverters are mounted, one on the end of each beam, and canted. Thus, the three mechanical inverters can also act as momentum wheels to control the solar panel assembly orientation.

Unfortunately, when these massive devices double as momentum wheels, it is not possible to have frequency and phase coherence in the output of the three inverters. Thus, each panel/inverter is considered as an independent, non-synchronized alternator, and the distribution assembly must be designed with this in mind.

A trade-off is necessary to select the method of transfer of power across the rotating joint. If slip rings are selected, they must handle large currents. An alternative is the Boeing-developed rotary transformer. Selection of the transformer would provide an additional degree of design flexibility in that a step-up or step-down transformation could be used to optimize physical parameters of the inverter to achieve orientation control without compromising the electrical performance.

Distribution Assembly. The distribution assembly is in two parts. Part A is integral with the solar power assembly and provides conditioned power to the sun orientation assembly, and the clock-drive for the rotation of the payload structure. Part B distributes power to the payload systems, and the payload mounting assembly subsystems, such as orientation/pointing and thermal control.

The distribution assembly also has a small battery pack to be used during the solar occultation periods. Occultation occurs twice per year (at the equinoxes), but only for a few minutes each day and only for a few days. The battery is used to retain pointing control; it is not sized to maintain payload operation during solar occultation.

Sun Orientation Assembly. The purpose of the sun orientation assembly is to maintain the pointing direction of the solar power assembly. The torque necessary to correct errors is provided by controlling, independently, the wheel speed of the three inverter momentum wheels. The sun sensors are solid-state devices that are mounted along the long axis of the solar power assembly. Several sensors in each of two directions would be used; a micro-computer would average the outputs and set the inverter's wheel speed.

Voltage Regulation. Due to the variation in load current, and the variation in wheel speed, several levels of regulation are required. It is proposed that each panel have both a coarse shunt regulator across the blanket strings, and a fine inverter current regulator. The blanket strings will not be consistent in output, and may vary from the nominal 2800 vdc by as much as ±50 percent. The shunt regulators (one per string) would maintain the string voltage to about ±1 percent of nominal.

Varying the wheel speed for reaction control will also cause the voltage (as well as frequency) to vary. This can be compensated by adjusting the field current. This same method would be used to compensate for load variations.

Although voltage regulation is not classified as a unique assembly, it is an important parameter for the payload systems design. Having a well regulated power source, each payload element power conversion element can be optimized for performance.

Platform System

The platform structure is a flat disc, gimballed to the mounting ring. On the front side are mounted the several antenna elements. Internally, and removable through the rear, are the corresponding electronic components. On the periphery is a standard docking ring used for servicing and LEO to GEO maneuvering. On the rear side are radiating elements for thermal control.

Platform Structural Assembly. The antenna platform consists of a center rectangular core structure that is 10 meters wide, 3 meters deep and 4.2 5 meters in length. On the pivot end, a counterweight power distribution compartment is attached. On the other end, a Shuttle-type docking ring is attached. The sides of the core have stub rectangular beams attached to act as firm mounts for the various antenna packages. On the reverse side from the antenna mounts, a truss structure is assembled to stand-off from the core by 6 meters (increasing the structural stiffness) to mount radiator panels for heat rejection. The center radiator panel has a powered longitudinal hinge in order to insure proper heat rejection under all conditions of sun attitude.

The core structure is fabricated from rectangular beams, diagonal bracing and skin panels, where needed. These beams may be packaged within the payload bay of the Shuttle or be manufactured in space by a *beam machine* and perforated coils of strip aluminum. Joint and fitting attachments are designed for Shuttle Remote Manipulator System assembly.

The main interface with the previously assembled turntable is at the pivot location between the counterweight compartment and the main core structure. This pivot will be eventually outfitted with electrical power and control cables fed thru the center of the two pivot bearings.

Orientation Control Assembly. The vector normal to the front side must be oriented in the meridian (96° west) plane, and the 40° north parallel (latitude) within ±0.01 degree (±36 arc-seconds); the 12 o'clock axis must also be in the meridian plane to about the same precision. The antennas, which are rigidly mounted, have a -3 db beamwidth of 0.28 degree; therefore, the platform should be held within 0.03 degree, rms error, to avoid signal degradation.

The different pointing orientations of the solar panel assembly and the platform assembly dictate a separate orientation control mechanism for each. The solar power assembly orientation system was described in the Power Generation Subsystem section; the platform assembly must be more precise and requires a ground reference better than horizon sensors.

The suggested approach would establish a pilot beam transmitter at the central ground location, and a crossed-baseline interferometer on the platform. A carrier frequency of 1.0 Ghz to 10 GHz would be suggested to minimize atmospheric refraction, and atmospheric absorption effects. An electromagnet wave with a GHz frequency has a half-wavelength of 15 cm, which represents the zero-order spacing of the antenna elements. Zero-order spacing would provide direction cosine resolution to about 1.0 degree; to achieve the desired 0.01 degree requires another set of elements (on the same baseline) spaced at about 100 wavelengths (30 meters), which is twice the diameter of the platform. A trade-off is required to establish the optimum parameters.

The interferometer establishes the normal vector orientation; another reference is needed to orient the 12 o'clock vector to the meridian plane. A star-tracker is suggested for this purpose. The reference star should be near the meridian, and near the celestial pole; Canopus, in the southern hemisphere has been used by previous space vehicles.

The needed torque would be provided by three control moment gyro's. Coarse movement for acquisition, and momentum-dumping would be provided by peripheral reaction jets.

The characteristics of the user ground terminals are summarized in Table 2.

The 100 Kilowatt Geosynchronous Platform

The baseline 500 kilowatt geosynchronous platform provides an impressive array of services for the people in the United States and the rest of the world, but it is also power-hungry and relatively bulky. An alternate approach would entail the use of a smaller less powerful platform which might eventually be widely duplicated several dozen times. The sketch in Figure 71 shows a 100

Table 2 Preliminary Design Selection Parameters for Geosynchronous Platform.

SERVICE	DOWN-LINK	UP-LINK	USER TERM	GND TERM
BROADCAST EDUCATION	20 GHz WBFM, 13 Beams 1 Channel	30-GHz WBFM, 1 Beam 1 Channel	Conv. TV with Converter and Antenna	Conv. TV, Live and Tape
POCKET TELEPHONES	20 GHz Dig Voice/Data FM, Mult. Access 30 GHz WB Multiplex Mult. Beams	20 GHz 30 GHz WB Multiplex 1-Beam	Hand-Held Unit, Battery Powered	Conv. Telephone Exchange
INFORMATION SERVICE	Pocket Telephones Link and/or Standard Phones		Intelligent Terminals to Central	Computerized Data Bank
TELECONFERENCE	Use BC Education	Add Multiple Beams/Channels	Conv. TV with Converter	Conv. TV, Live
ELECTRONIC MAIL	20 GHz 50 Mbps	30 GHz 50 Mbps	Photocompositor at Local Post Office Over Optic Cables; Distribution by Local Postman	Magnetic Tape or Optical Readers at Region Center for Distribution or Relay to Other Centers.

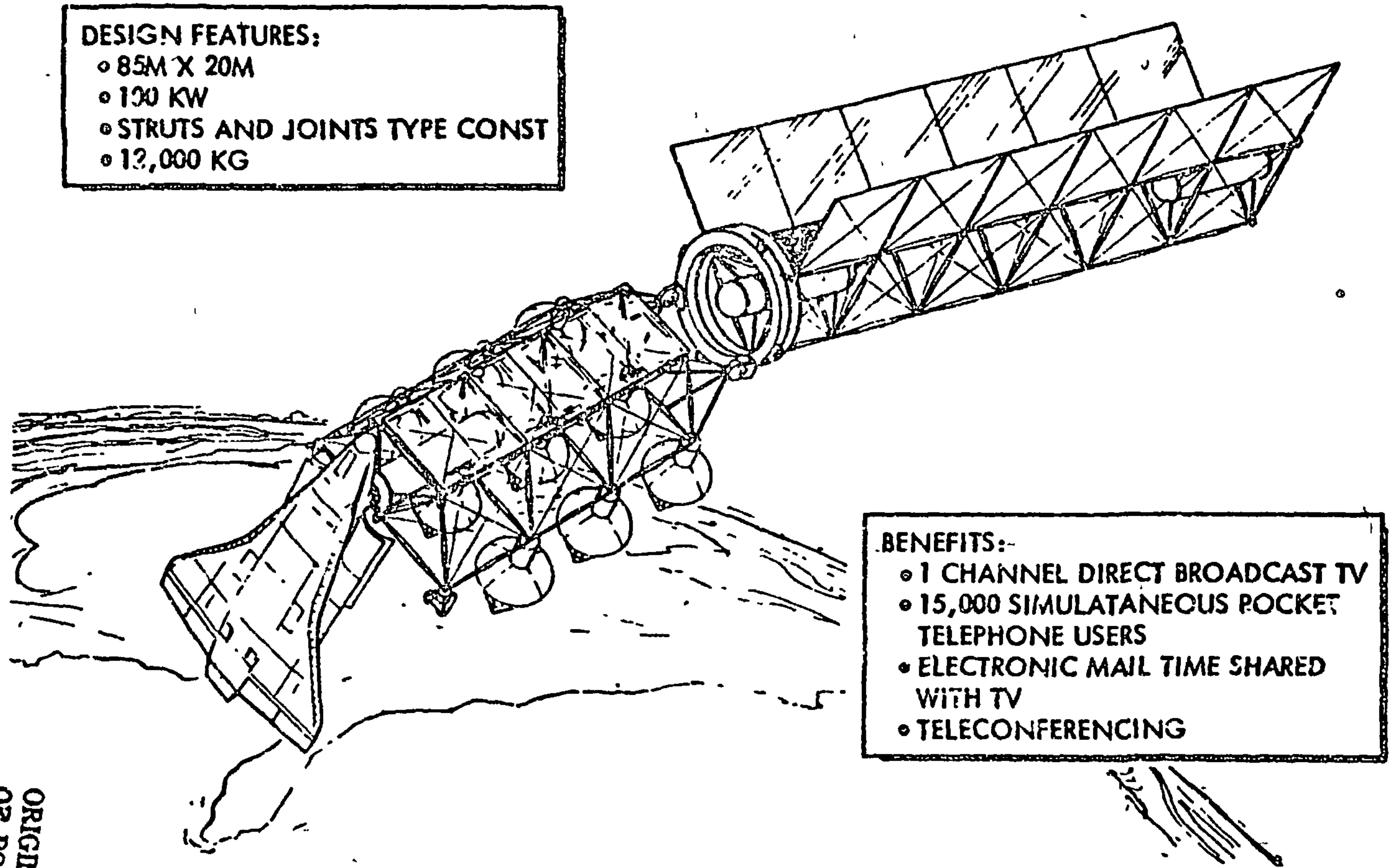


Figure 71. 100 kW Geosynchronous Platform

kilowatt platform with capabilities that are structured along these lines. For example, rather than providing five channels of T.V., it provides only one and rather than handling 45,000 simultaneous pocket telephone conversations, it handles 15,000. In addition, it time-shares power by restricting the electronic mail services only to off-peak hours.

The result is a platform (shown in Figure 72, Dwg. 78255-003) that is smaller, less complex, and considerably lighter than the 500 kW version. However, in view of the restricted services, it is not as light as might be hoped. Although it provides only one-third to one fifth the services of the 500 kW platform, it weighs almost half as much. Moreover, it puts more stringent demands on some of the ground equipment which would raise its price. Thus, as would be expected, the smaller version is a viable possibility despite the fact that it loses some of the economies of scale.

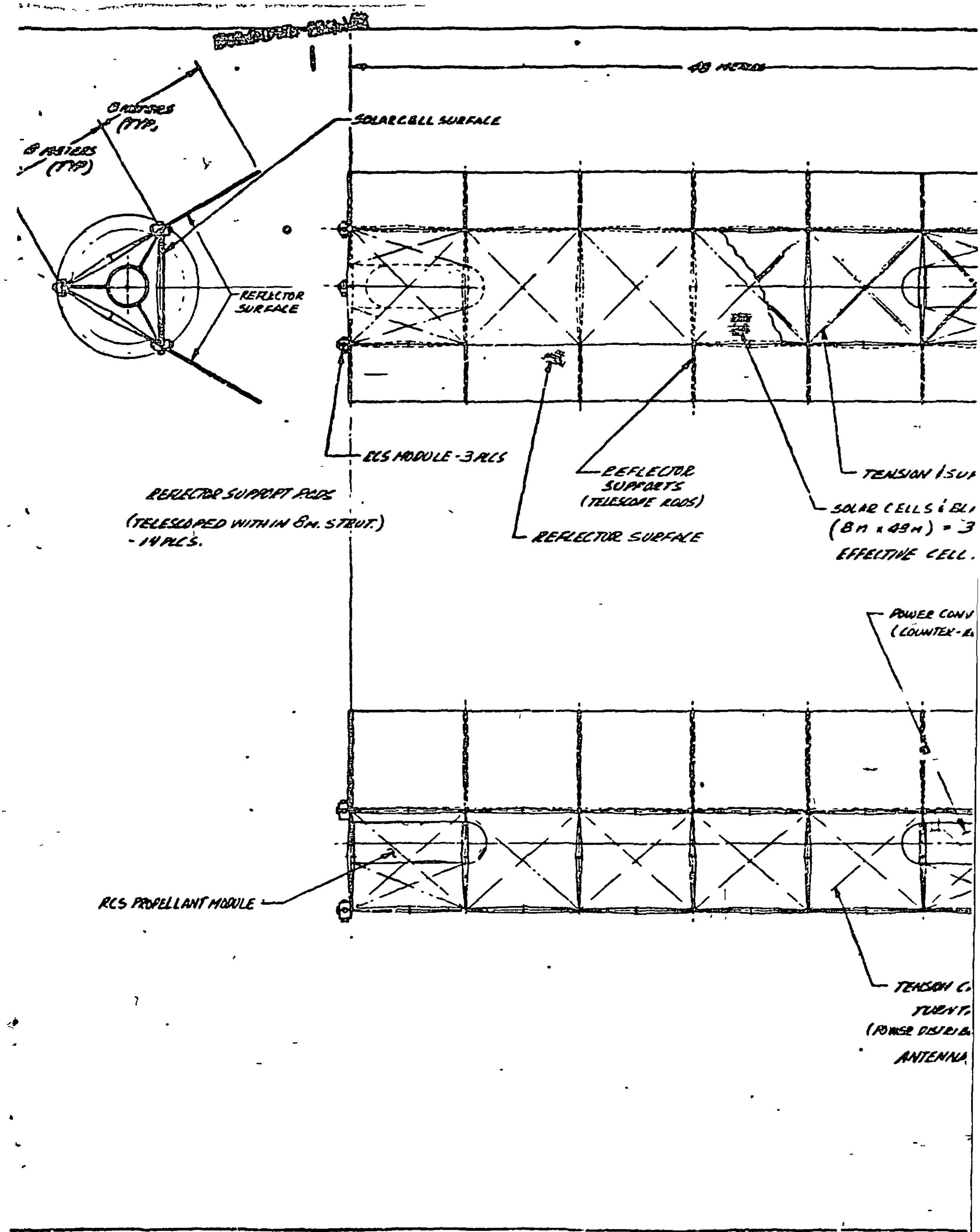
Platform Design Philosophy

The advantageous properties of multifunction, geosynchronous platforms have been adequately documented in the previous sections of this report. Unfortunately, such a platform also involves certain intrinsic disadvantages. These include more complex institutional and political arrangements and difficulties with mutual illumination of the various types of antennas. In addition, the integrated design suffers from the fact that the most stringent mission requirements (e.g., spatial location, stationkeeping and inclination control) must be imposed on all the mission elements.

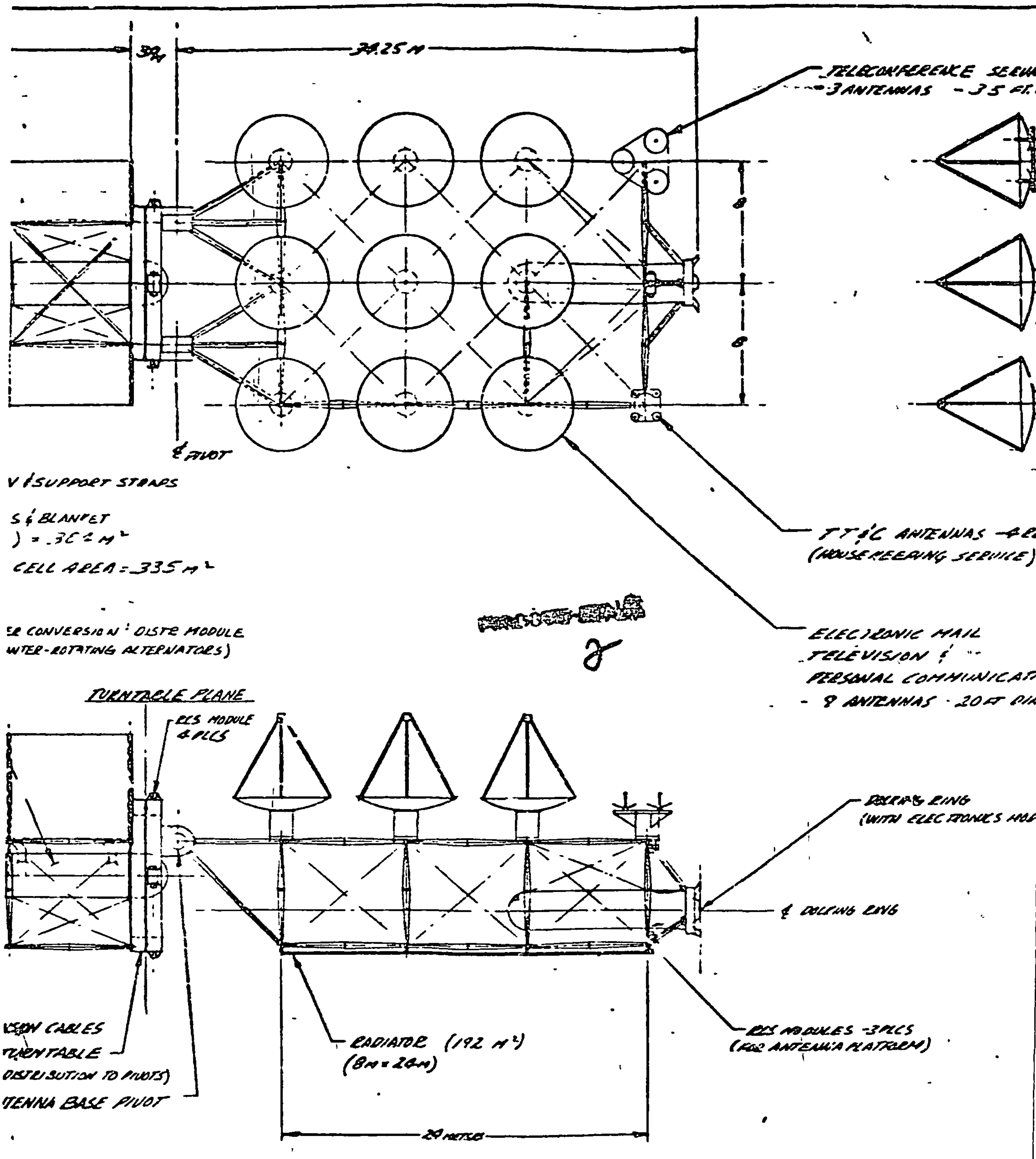
Another crucial problem centers around the difficulties of insuring centers around the overall reliability of these complex and vital services. Some observers express concern that a failure in the hardware devoted to one of the major services could cause permanent failure in the overall system. The disruption that would then result could be intolerable to a complicated industrial society. Although communication satellites have evolved with extremely high reliability levels, this is a valid worry. One way to minimize its likelihood and its impact is to utilize a series of scaled-down satellites each of which performs either a dedicated service or a relatively small number of separate services. The result should be an overall system that would then experience not total failures, but only graceful degredations. However, as has been shown, this solution would substantially increase the total weight and cost of the overall system.

Another crucial tradeoff is intimately interlinked with system reliability It involves the possibilities for using remote teleoperators versus manned maintenance repair and modification services. Teleoperators would most likely be far cheaper than manned systems, however, there are questions as to whether they can perform the necessary functions in an efficient and reliable way. Manned systems are more desirable in many respects, but far more costly and they cannot be made available in the same early time frame.

Services are obviously a pacing item in the future of *space industrialization*, and multifunction communication platforms seem to have many advantageous properties. However, they also give rise to certain unexpected difficulties.



49 METERS
8 METERS (TYP)
8 METERS (TYP)
SOLAR CELL SURFACE
REFLECTOR SURFACE
RCS MODULE - 3 PLCS
REFLECTOR SUPPORT RODS
(TELESCOPED WITHIN 8M. STRUT.)
- 14 PLCS.
REFLECTOR SUPPORTS
(TELESCOPE RODS)
REFLECTOR SURFACE
TENSION / SU
SOLAR CELLS & EL
(8M x 49M) = 3
EFFECTIVE CELL.
POWER CONV
(COUNTER-
RCS PROPELLANT MODULE
TENSION C
TURNT
(POWER DISTRIB
ANTENNA



39 M
39.25 M
TELECONFERENCE SERVIC
-3 ANTENNAS -35 FT.
8
8
¢ PIVOT
V ¢ SUPPORT STRAPS
S ¢ BLANKET
) = 3CC M²
CELL AREA = 335 M²
ER CONVERSION: OISTE MODULE
NTER-ROTATING ALTERNATORS)
TT¢C ANTENNAS -4 PL
(HOUSEKEEPING SERVICE)
ELECTRONIC MAIL
TELEVISION ¢
PERSONAL COMMUNICATI
- 9 ANTENNAS - 20 FT DIA
TURNTABLE PLANE
RCS MODULE
4 PLCS
DOCKING RING
(WITH ELECTRONICS HOA
¢ DOCKING RING
SION CABLES
TURNTABLE
DISTRIBUTION TO PIVOTS)
TENNA BASE PIVOT
RADIATOR (192 M²)
(8M x 24M)
RCS MODULES -3 PLCS
(FOR ANTENNA PLATFORM)
24 METERS

2

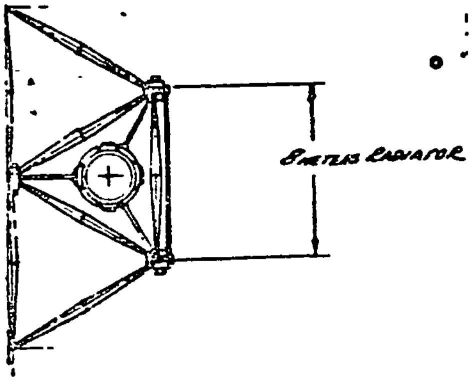


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Figure 72.

ROCKWELL INTERNATIONAL CORPORATION
SPACE DIVISION

DATE 11-28-77

GEOSYNCHRONOUS ORBIT PLATFORM
STRUT BRACED "MINI" P.S.P.
(100 KW POWER EOL)

78255-00.

Within the context of this broad *space industrialization* study it was not possible to consider even the issues identified above in a sufficiently detailed way. However, these issues and most likely others are crucially important and it is our recommendation that they be addressed in detail in subsequent studies.

HIGH INCLINATION ORBIT FACILITIES

The satellites located in high inclination orbits are imminently suited to repetative, close-range observation of the earth over a period of a week or two. Satellites of this type include advanced versions of the Landsats and Seasats, as well as some elements of the global weather and resource base.

One advanced observation satellite, the Landsat D, is sketched in Figure 73. As can be seen from the descriptive material in the figure, this space vehicle weighs 145 kilograms and carries 84 separate detectors. The spatial resolutions and the interfaces between the Landsat D and other space vehicles are also sketched in the figure. Significant improvements in its sensor capabilities can be provided by the more advanced earth observation satellites which are discussed in the next few major subsections.

<u>Repetitive Earth Observations</u>

During the course of the *Space Industrialization* study, eight observation objectives were identified. These can be divided into two non-overlapping groups — repetitive, indicating an update scan of weekly or seasonal rates, and a *one-shot* mapping that may not scan more than once per decade. The latter are obviously candidates for short-life, recoverable, dedicated satellites, not necessarily integrated into one vehicle. The former are more on the order of semi-permanent, multipurpose, perhaps, replicated or in multiple orbits.

These missions with repetative objectives can be listed as follows:

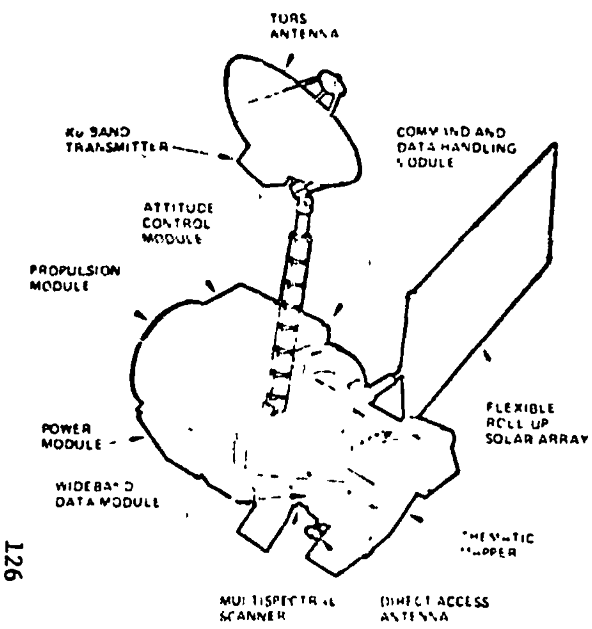
1. Crop measurement (global)
2. Ocean resources/dynamics
3. Water resources (land) and run-off forecasts
4. Global effects monitoring

These objectives can be fulfilled to a degree by the sensor technology which is being developed for Landsat. In general, this technology includes methods for making observations in the electromagnetic spectrum from radio (millimeter) to U.V., divided into suitable wavelength bands.

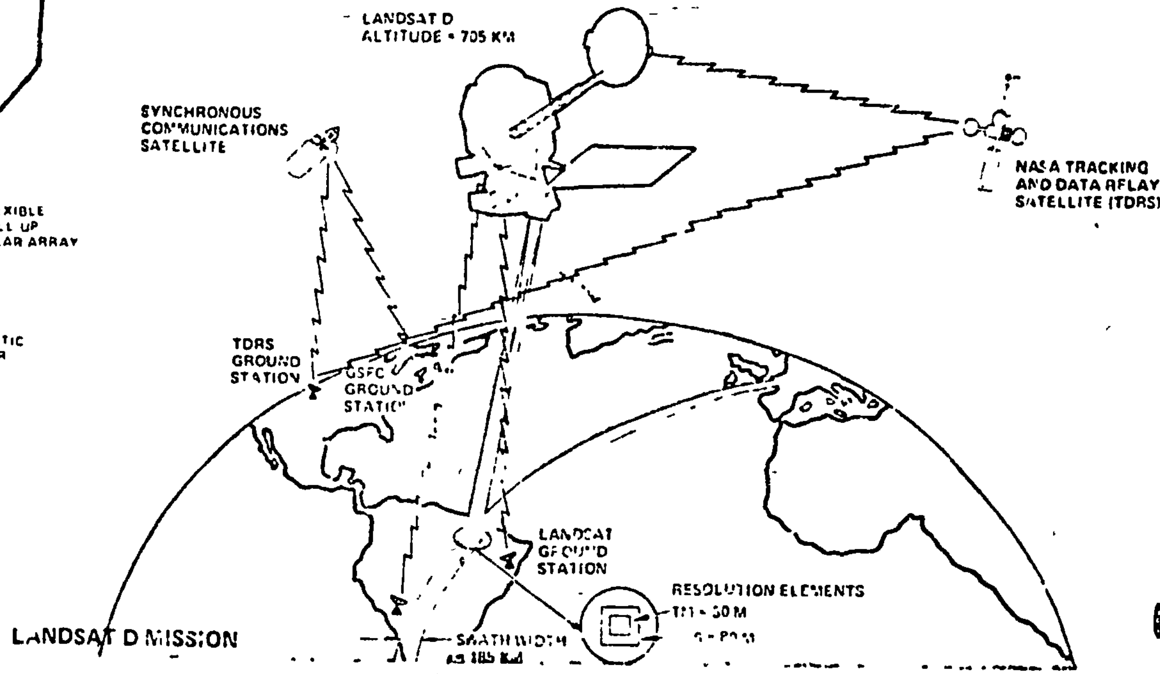
<u>*One-Shot* Earth Observations</u>

The *one-shot* (or infrequent) earth observations can be listed as follows:

1. Oil-mineral location
2. Topographic mapping
3. High-resolution resource mapping
4. High-resolution radar mapping



LANDSAT D



DELTA 3910 LAUNCH
TDRS COMPATIBLE
SHUTTLE RECOVERY CAPABILITY
MAXIMUM WEIGHT 3660 LBS.
ALTITUDE 705 KM
POWER ≤ 1500 WATTS

PHYSICAL CHARACTERISTICS

	TM	MSS		TM	MSS
No detectors	84	26	Length, in	77	50
Operating power, W	190	65	Width, in	24	21
			Height, in	39	23
Weight, kg	145	65	Scan mirror, in	21	13

Figure 73. Landsat D Overview

In general, these objectives can be fulfilled by photographic sensors (passive) and radar (active) sensors. Their intended result is an image that is directly related to the terrain and precision surveying. Operationally, these sensors could be injected into a low altitude orbit where they can collect data for one complete global survey, then be recovered to process the data.

Tables 3 and 4 identify typical sensors applicable to each objective, and their pertinent characteristics, in so far as they are definable. Since the microwave radiometer antenna is so large in comparison with the other sensors, it seems desirable that this sensor should be placed on a separate platform. This is the approach that was alternately taken in the *Space Industrialization* study efforts.

Earth Observation Platform

The earth observation platform (see Figure 74) is configured as a versatile sensor platform that is Shuttle-launched and capable of gathering thematic and multispectral data similar to that obtained from Landsat D. The increased spectral capability is obtained from three thematic mapping installations, two multispectral camera positions and two return-beam vidicon equipment locations.

The platform shown in detail in Figure 75 (Dwg. 78255-006) utilizes space-proven equipment from the Landsat series of satellites. Improved subsystems in the area of data handling, recording, solar array power generation and attitude control all contribute to a significant increase in the mean-time-between-servicing and multi-frequency information retrieval.

The structural hardback of a triangular shape has been retained (similar to previous satellites), however, the length and support provisions for the TDRS antenna, as well as the solar array has been changed from Landsat D configuration. Provisions for various propulsion modules and Shuttle-mounted module exchange hardware has been retained.

Total overall weight is estimated as 4000 kg — about 30 times the weight of the Landsat D. Additional weight (chargeable to payload) of the Shuttle support cradle, sensor services during launch, wire harness installation in the payload bay may be expected to be well within the Shuttle launch and retrieval capability.

The thematic mapper information growth will be increased to 252 detectors and 21 bands. The multispectral scanner information will increase by a factor of two over Landsat D information. Major performance improgements and utilization of selected frequencies may be expected over the life of this satellite platform.

The Shuttle launch configuration of the earth observation platform is sketched in Figure 76. As can be seen, the space vehicle fits snugly into the Shuttle cargo bay.

Table 3. Sensor Types for Various Missions

OBJECTIVE	RADAR	IR SCAN	TV CAM	MS CAM	MW RADIO.
REPETITIVE					
Crop Measurement (Global)			X	X	
Ocean Resources & Dynamics		X			X
Water Resources (Land) Run-Off Forecast			X		X
Global Effects				X	X
ONE-SHOT					
Oil/Mineral Location	X		X		
Topographic Mapping	X		X		
Resource Mapping	X		X		
Radar Mapping	X		X		

Table 4. Earth Observation Sensor Characteristics

SENSOR	CHARACTERISTIC	WEIGHT KG (SIZE)	POWER KW	RESOLUTION	SWATH	DATA FORM	QUANTITY	$1.0M
RADAR, (SAR)	Active Mapping	1170 ($3.6\ M^3$)	2.4	15 M	90 KM	Film 9.5"	1 per min	20
HI RES IR SCANNER	IR Emissions	155 ($4.0\ M^3$)	0.25	10 M	40 KM	Film 5"	1 per sec	3.1
I.D. CAMERA	Mapping	56 ($0.3\ M^3$)	0.09	0.3 M	800 KM	Film	1 per 18 sec (Stereo)	8.0
MULTI SPECTRAL CAMERA	E.M. Emission Survey	155 ($1.3\ M^3$)	0.16	1.0 M	400 KM	Film 70-MM		4.0
MULTI FREQUENCY MW RADIMETER	Temperature Measurements	8×10^5 50 M Dia 25 M Len	?	200 M	800 KM	Digital	About 10^3 bits/sec	170

*Abstracted from *Solar Terrestrial Observatory Requirements*, by P. Fagan, Rockwell International, Space Division (June 6, 1977).

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Rockwell International
Space Division

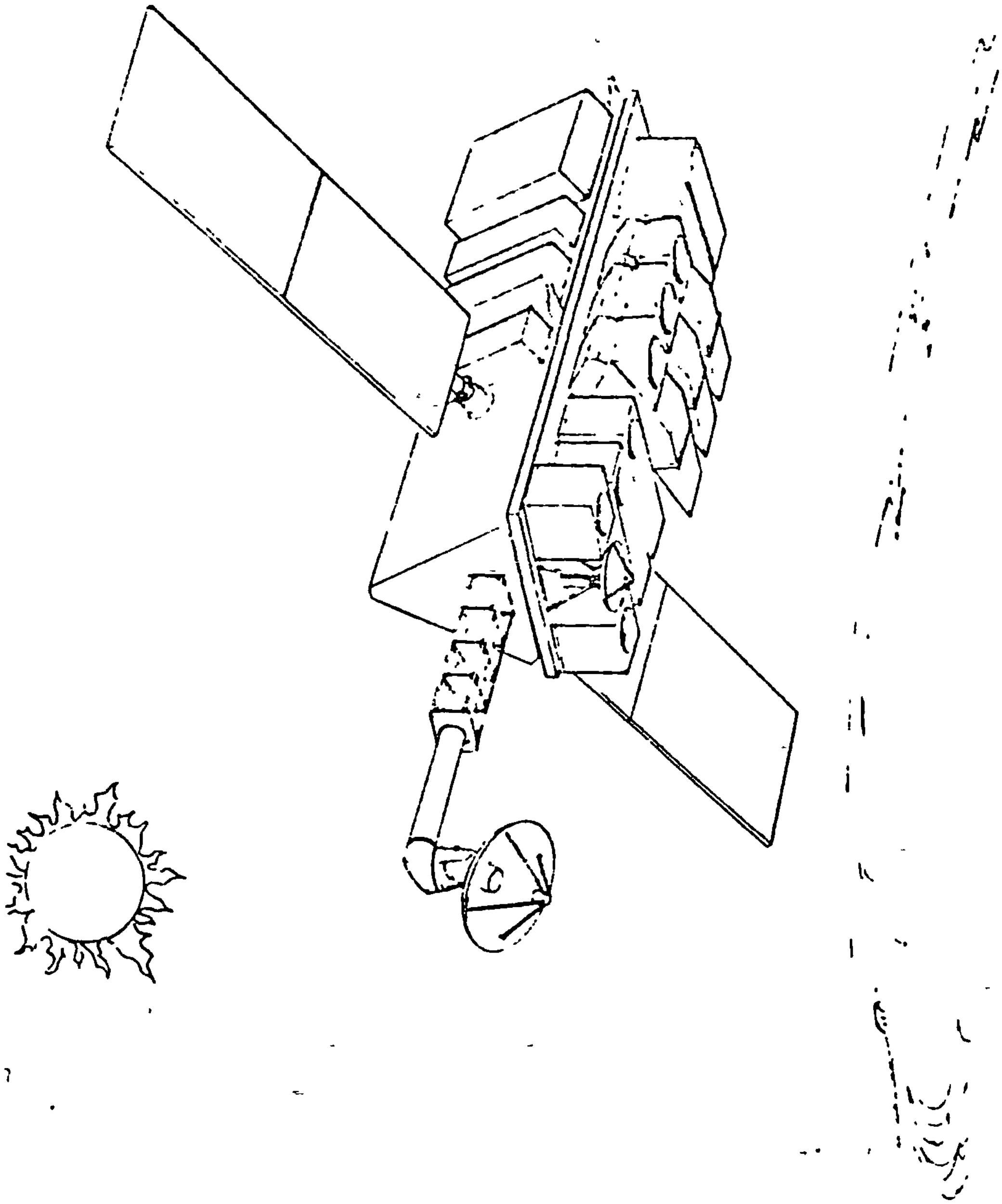
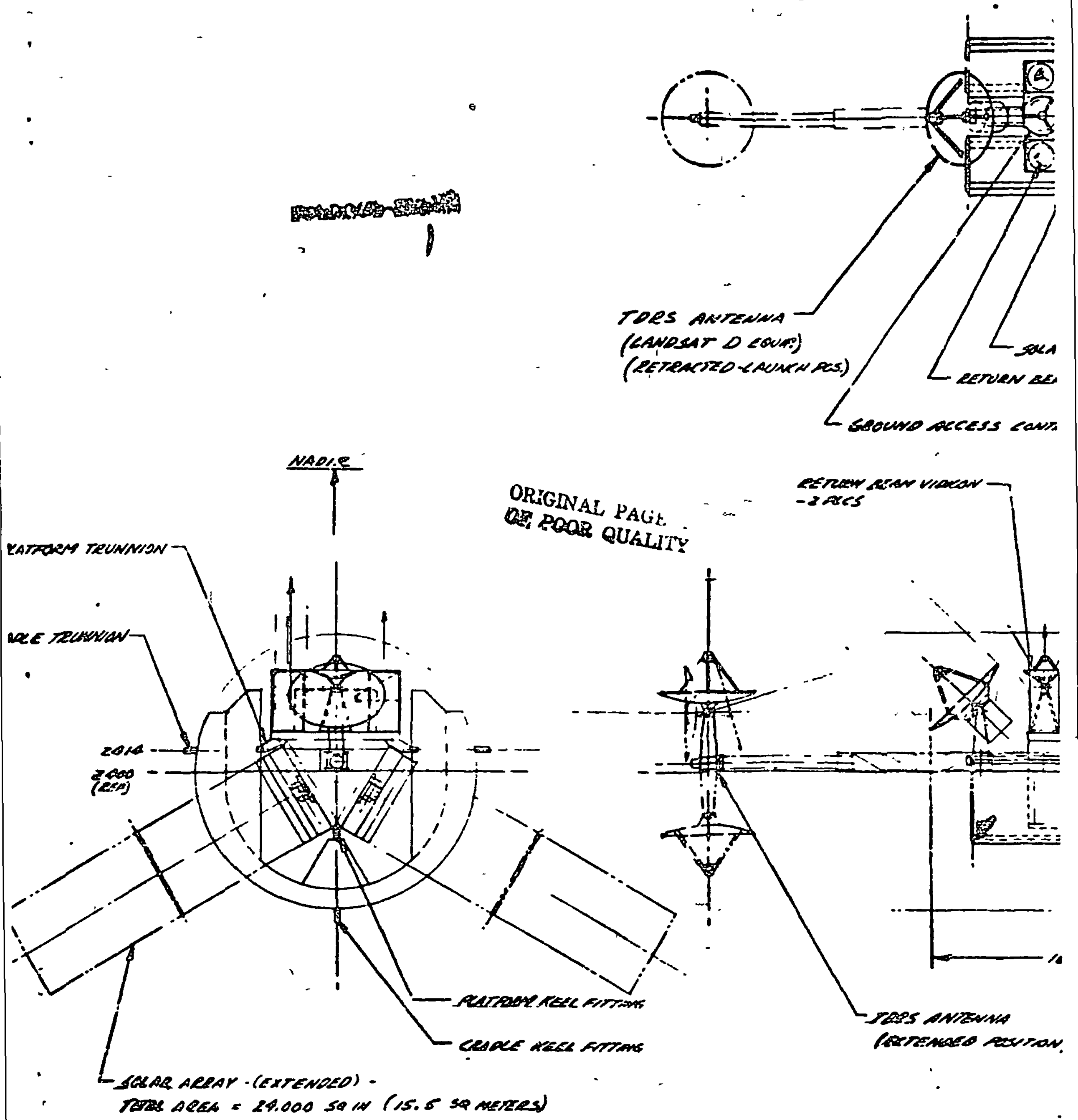


Figure 74. Earth Observation Platform


TDRS ANTENNA
(LANDSAT D EQUIP.)
(RETRACTED-LAUNCH POS.)
RETURN BE
GROUND ACCESS CONT
NADIR
RETURN BEAM VIDICON
-2 PCS
ATFORM TRUNNION
LE TRUNNION
2014
2000
(REF)
PLATFORM KEEL FITTING
CRADLE KEEL FITTING
TDRS ANTENNA
(EXTENDED POSITION,
SOLAR ARRAY - (EXTENDED) -
TOTAL AREA = 24,000 SQ IN (15.5 SQ METERS)

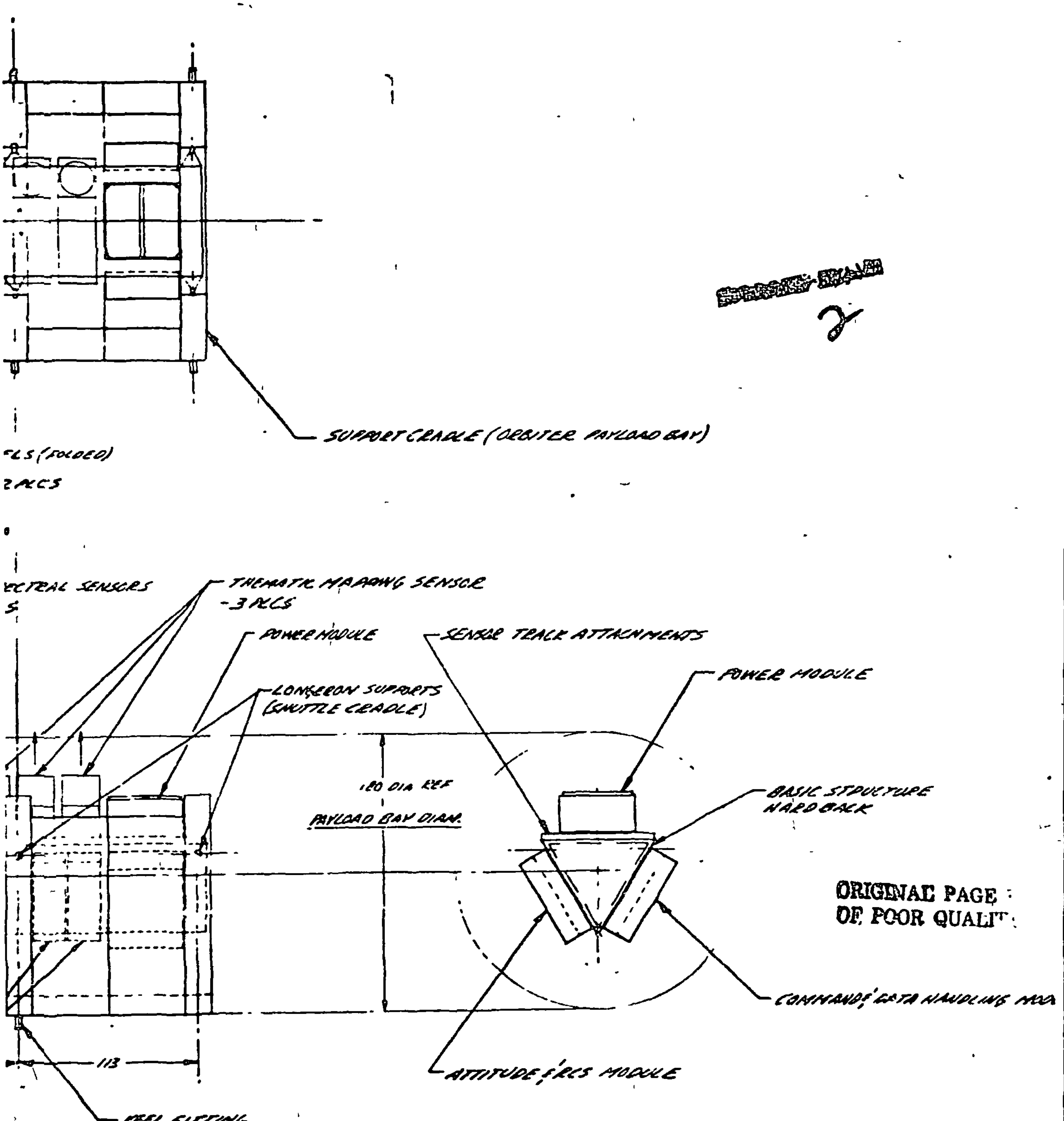


Figure 75.

ONICS MODULES
MUNICATIONS & SENSOR DATA
OOR SUPPORT
CORDERS

SCALE 1/40	T. SHIRAI 2-1-76	ROCKWELL INTERNATIONAL CORPORATION SPACE DIVISION
EARTH OBSERVATION PLATFORM - THEMATIC MAPPING & MULTISPECTRAL SENSORS		78

131,132

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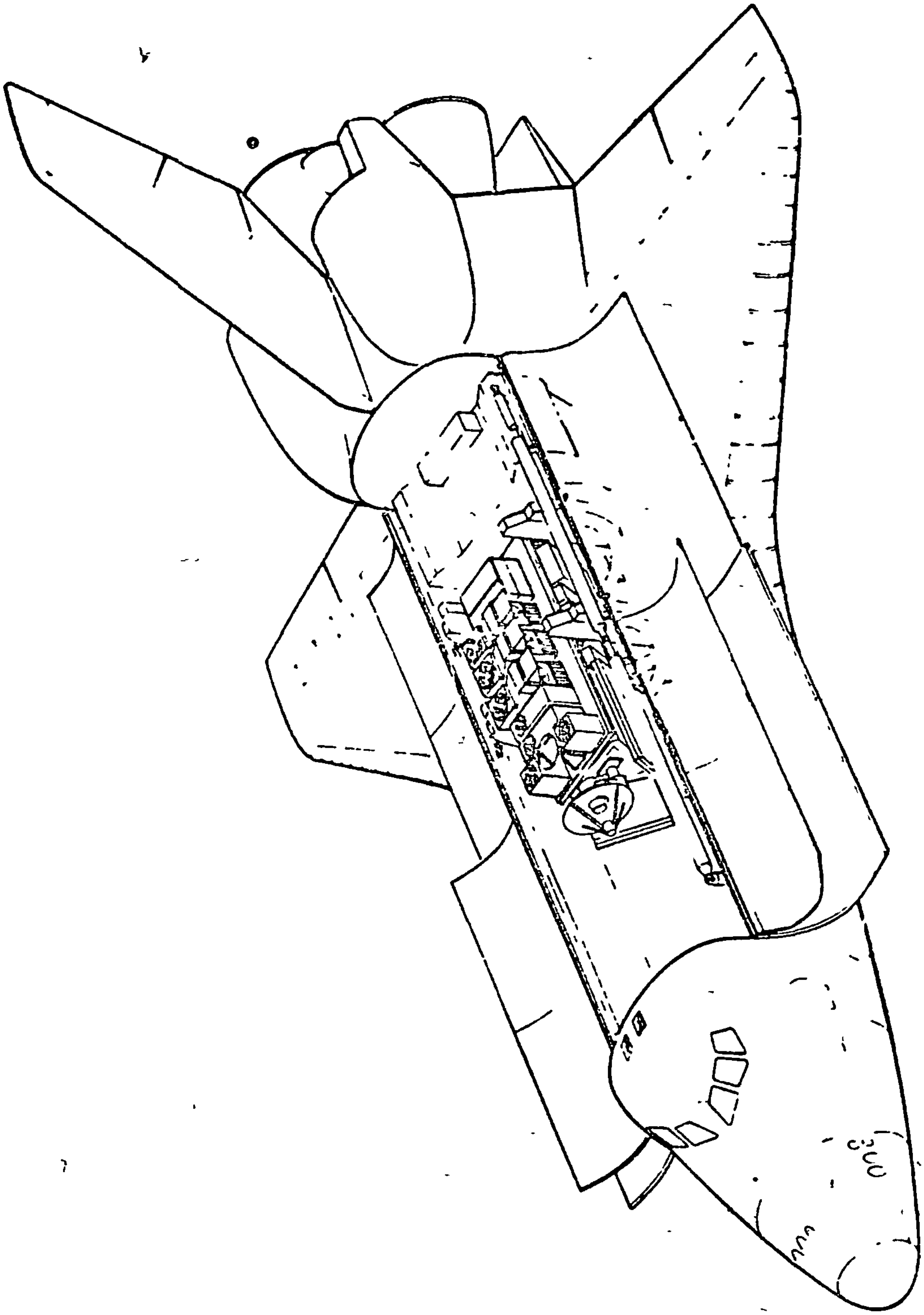


Figure 76. Earth Observation Platform in Launch Configuration

One-Time Observation Satellite

The one-time observation objectives can be satisfied by a Shuttle-launched high-resolution radar supplemented by an optical identification or metric camera. As in the repetitive objectives, the radar completely dominates the vehicle design, in the size of the antenna and the power required. In addition, there are significant data processing and data storage problems to solve.

At this time, no realistic preliminary design data has been uncovered other than that of a prototype suggested by Ivan Becky's Aerospace report. For this reason, a basic engineering mission and radar data analysis was conducted on the following specifications:

High-Resolution Side Looking Radar

Orbit, polar	925 km (103 min. period) 99.15° incl.
Swath width	370 km
Resolution	15 meters
Array	3 meters by 15 meters
Prime Power	12 kW

Engineering Analysis

A quick analysis of the geometry indicates that for a 925 km altitude, the distance (range) to the horizon is about 3300 km, and the *downward* look angle to the horizon is 63 degrees.

If such a vehicle utilizes a repetitive pulse rate of 900, there will be *holes* in the plot representing the transmitting time. These holes would have their intensity (in reception) reduced by the inverse of the duty cycle, thus the duty cycle should be quite small, at least 1:100.

The lack of design data in this description dictates the following assumptions. We can assume that the 10 x 50 dimensions represent the antenna array, and that this is oriented with the 15 meter length in the direction of the velocity vector. We can also assume that the carrier frequency would be chosen in or near L-band, e.g., 1.2 GHz. This would help minimize the atmospheric refraction and absorption.

At a 925 km altitude (103 minute period), the subsatellite track speed is about 7000 meter per second; to obtain 15 meter resolution, the pulse rate should be about 900 pps, and as short as possible. The travel time (2-way) from the radar to the nearest ground point is about .006 second, so the minimum integration time (interval between pulses) is somewhat greater. The reason is that the pulse must be directed in the forward direction (so called *squint*); in fact, side looking radar systems work best when the look-angle is almost at grazing incidence to the horizon.

Of course, the *squint* angle should be determined by how long the pulse requires to return from the horizon, and the amount the subsatellite point advances in this time. The two-way time for horizon range is about 22×10^{-3}

seconds. In this time, the subsatellite point will advance by about 150 meters. Compared to 1900 miles, this is insignificant, so it can be neglected in all subsequent calculations.

Since the two-way travel time is 22 milliseconds and the pulse period is 1.1 milliseconds, some 22 pulses will be transmitted before the first pulse returned. In this time, the spacecraft will advance about 185 meters in its orbit.

The antenna length of 15 meters is effectively multiplied by the number of reflected pulses it can receive. Each ground point acts as a reflector, varying from diffuse to specular; specular reflections are intense, but only over a limited angle; diffuse reflections are less intense, but are reflecting in all directions, corresponding to a cosine law distribution, and so are about equally effective as a specular surface. The limit of visibility is set more by the antenna directivity than the reflector's surface characteristic. For an L-band antenna, 15 meters long, the gain should be about 60 (14 db) and the beamwidth about 6 degrees.

To put it differently, the receiving antenna is (for a 3300 km range) equivalent to 35 kilometers in width. For shorter ranges, the equivalent length is proportionally less. While this is not a real design, it points out the most interesting factor of a side looking radar system — that the limiting range is not by the common inverse fourth-power law, but more nearly an inverse square law, because at greater ranges more pulses are received.

It is interesting also that the angular resolution of a side looking radar does not degrade with increased range. With the proper image processing algorithm, the final result is equally *sharp* over the entire frame.

It the satellite is placed in an orbit at 925 km altitude, it will cross the equator (assuming polar orbit) every 25.75° in longitude, which is about 3700 km along the equator. Thus, the projected swath width (3300 km) and the successive nodal crossings (3700 km apart) are compatible so that in one 12-hour mission the radar would map the entire globe one time.

Concluding Remarks

Based on the previous engineering treatise, it is suggested that this one time mission be performed by a descrete Shuttle payload mission. The antenna assembly could be installed in the Shuttle payload bay, orbit at a lower altitude for five to seven days, and accomplish the same objective.

To accomplish this one-time data gathering mission, the Shuttle would have to be reconfigured for additional electrical energy — about 1500 kW hours (12 kW x 24 hrs x 5 days). Two mission power kits of 840 kW hrs each would be adequate for this requirement. The 12 kW estimate included the spacecraft services of communications, processing and stabilization.

Considering the above engineering analysis and a proposed use of the Shuttle, no satellite has been designed to accomplish these one time objectives. It should be mentioned that only one Shuttle mission is required and that all data may be recorded and film is available for immediate return for processing and analysis.

Large Radiometer

A sketch of the large microwave radiometer is presented in Figure 77. Although it is much smaller than the hardware associated with some of the energy options, it represents the largest sensor structure that has been envisioned in this *Space Industrialization* study. The radiometer is a linear phased array with a cylindrical parabolic reflector that has an aperature of 200 meters by 262 meters. The linear array serves as a line source feed along the focal line of the linear parabolic reflector. The array forms the beams in the transverse plane over a ±15 degree scan angle.

As shown on the drawing (Figure 78), the radiometer contains essential elements of structure, mechanisms for figure control, electrical power generation by two 25-kW power modules, stabilizing momentum wheels and altitude control equipment, as well as a complement of earth observation sensor cameras. The sensors and housekeeping functions of the configuration are serviced by the docking of a Shuttle orbiter to the center docking port. The overall weight has been estimated at 256,284 kg (565,000 lb).

Construction would be from Shuttle-supplied materials and by operation of a compliment of beam-forming machines on orbit. The reflector surface as well as the shield panels are designed to be delivered in a rolled-carpet configuration out of the Shuttle payload bay. All other equipment to be emplaced is also compatible with Shuttle launch capability.

Thermal signature data from the earth surface may be collected in the discrete frequencies of 1.4 GHz, 4.99 GHz, 10.7 GHz, 18 GHz, 22 GHz and 35 GHz. This temperature data is considered to be of value in determination of soil moisture, water and ice boundaries, sea and surface temperatures, ocean current mapping and mixing phenomena of the atmosphere.

Data Delivery to the Ground User

With the advent of increasingly larger observation platforms equipped with large numbers of sensors, the problem of transmitting the extra data to the ground users on the available bandwidths of the RF spectrum becomes increasingly difficult. There are three seemingly viable approaches to solving or circumventing this problem that received brief attention during the course of the *Space Industrialization* study efforts:

1. Put a service astronaut on board the platform together with extensive computer hardware and software to compress the amount of data that is to be transmitted to the ground-based users.

2. Put astronauts anywhere in space together with extensive computer facilities and pump the data to him using geosynchronous relay satellites equipped with high-data-rate lasers. After suitable compression, data summaries would be transmitted to the ground.

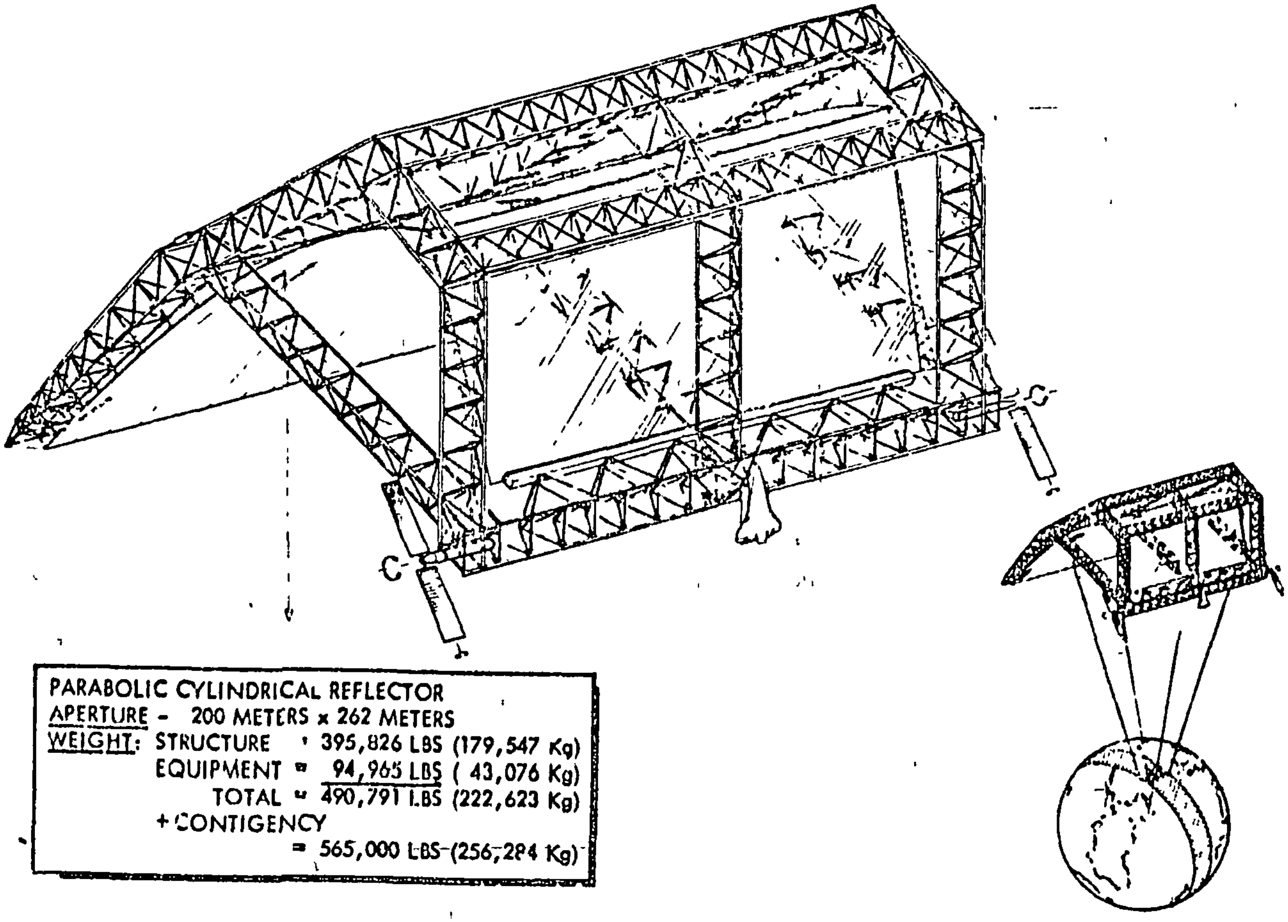


Figure 77. Microwave Radiometer - Earth Observations

3. Pump the data to a desert station via geosynchronous relay satellites with lasers. For rainy days in the desert, a tethered balloon would be sent above the cloud layers and the data would be pumped to the ground through fiber optics bundles running the length of the tether.

These options were briefly explored but not enough attention was devoted to them to resolve which (if any) is a viable option.

SPS DEVELOPMENT ACTIVITIES

Except for the Soletta, the SPS is the most ambitious of all the initiatives that have been advocated as a part of the *space industrialization* efforts. Since the SPS plays such a pivotal role, it is discussed in detail in the following subsections. The material that is presented was extracted from a preliminary draft of the SPS Executive Summary, which is being published by the Rockwell International analysis team as part of the SPS study contract.

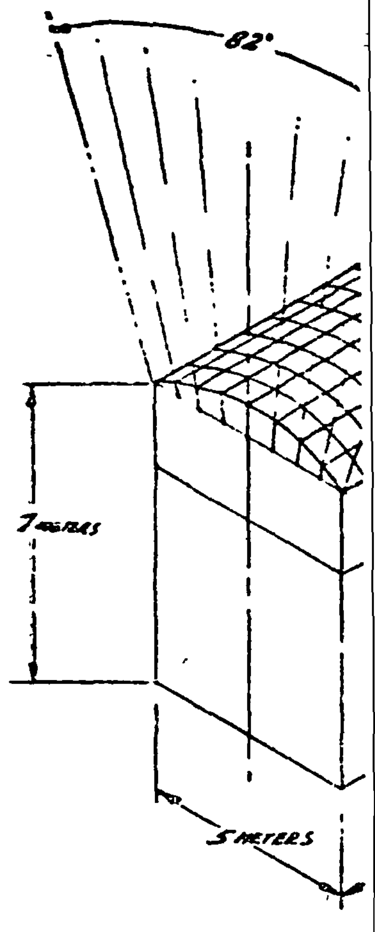
SPS Design

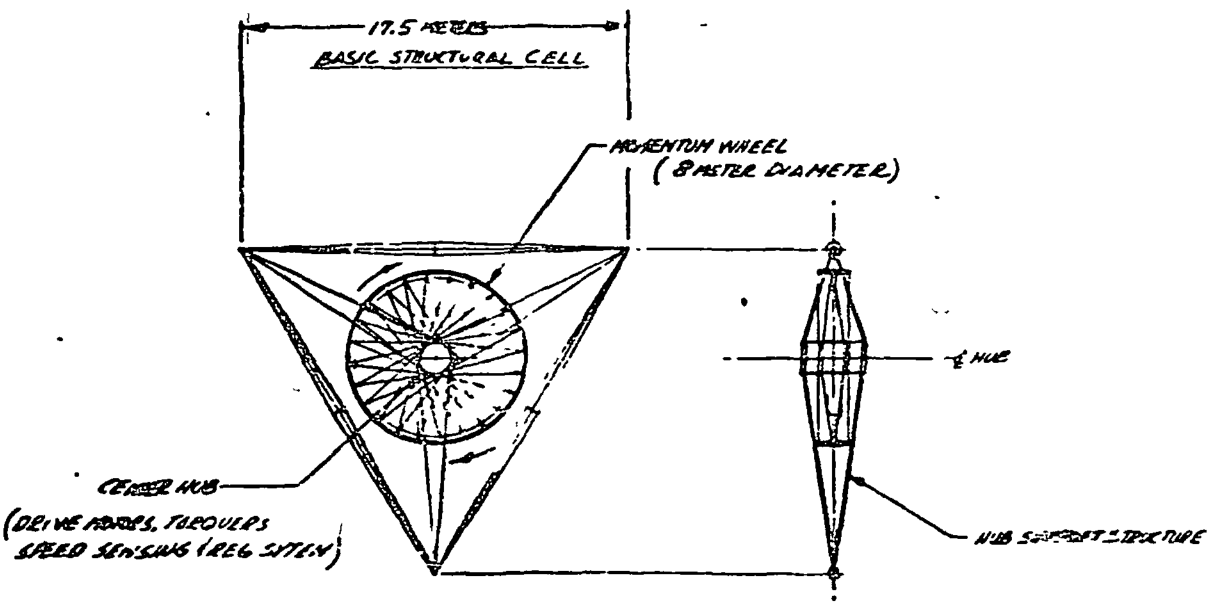
The photovoltaic concept for the SPS is sketched in Figure 79. This particular version was at the geosynchronous altitudes. It utilizes a three-trough configuration and delivers 5 GW to the utility interface on the ground. It has a single centrally located microwave antenna.

GaAlAs solar cells are used to produce the power using concentrators that give a 2:1 concentration ratio. A more detailed description of the system and subsystems is given in Table 5.

Figure 80 shows the end-to-end efficiency chain for the recommended baseline concept which has been sized to provide 5 GW of electric power to the utility busbar. With an overall efficiency of 6.08 percent, it is necessary to size the solar arrays to intercept 82.2 GW of solar energy. The quoted efficiency is the minimum efficiency, including the worst-case seasonal variation (91 percent), the end-of-life (30-year) concentrator reflectivity (86 percent), and the end-of-life (30-year) solar cell efficiency (15.2 percent).

A summary of the satellite mass properties is presented in Table 6. The two major segments, the collector array and the antenna section, are nearly equal in mass. The major contributor to the collector array mass is the power source, which includes the solar blanket and the reflectors. The solar blanket is the predominant mass. Antenna section mass properties are driven by the microwave power segment which includes the RF radiators and the klystrons. Total structure and mechanism mass is approximately 20 percent of the satellite dry weight. Total satellite weight, including a 30-percent growth factor, is 36.5-million kilograms. Propellant resupply for attitude control and stationkeeping is a very small annual mass compared to the satellite mass.





MOMENTUM WHEEL - 2 RCS

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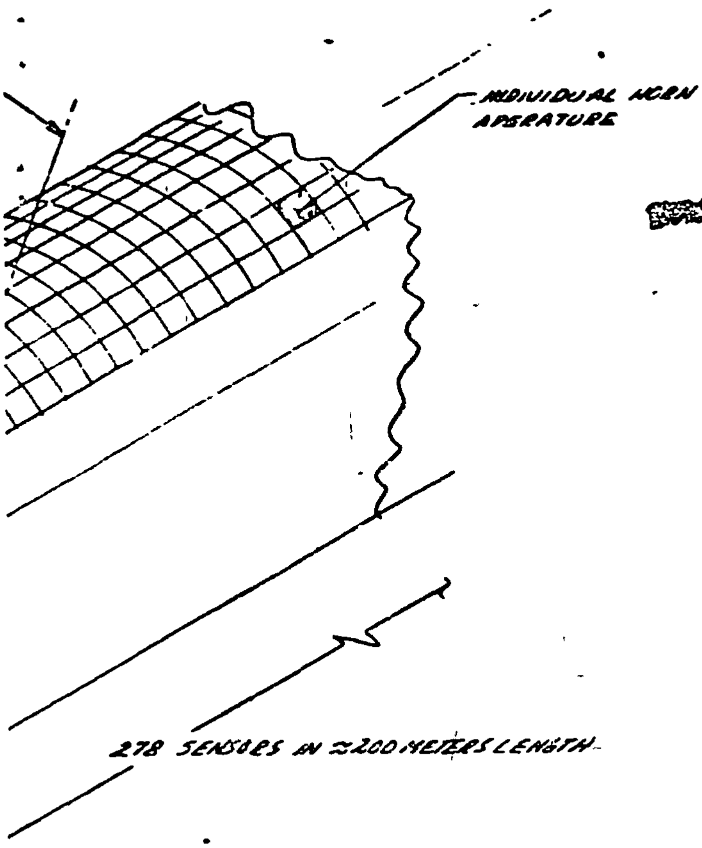

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VE LINEAR SENSOR ARRAY

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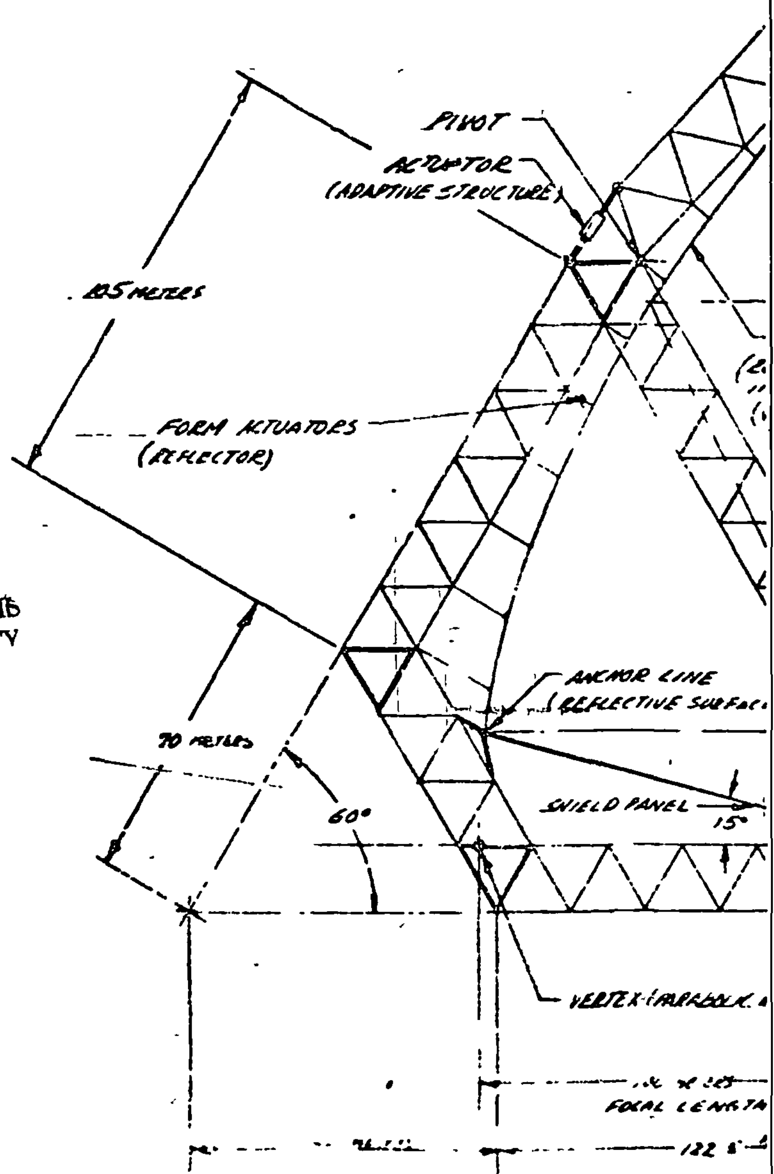

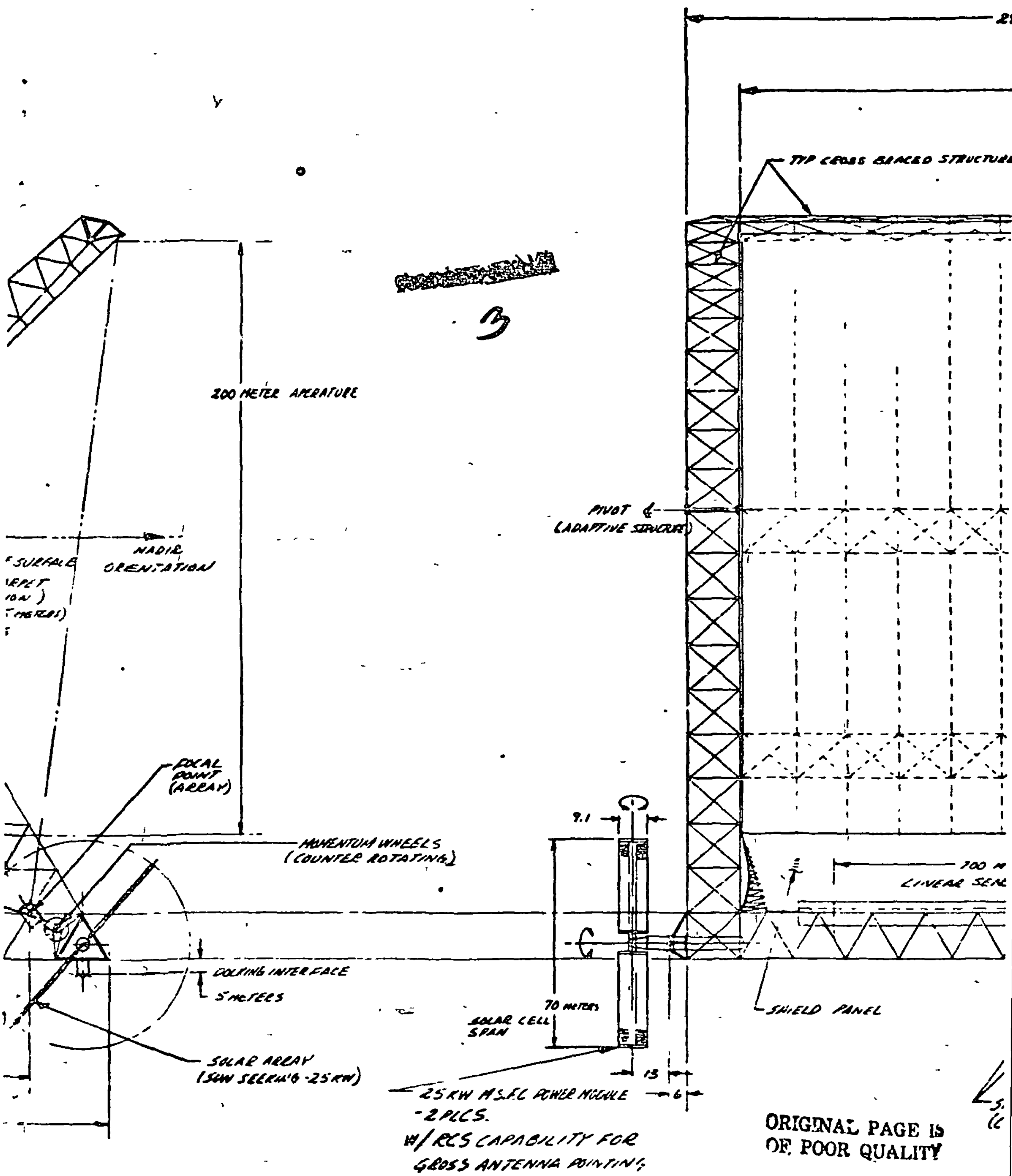

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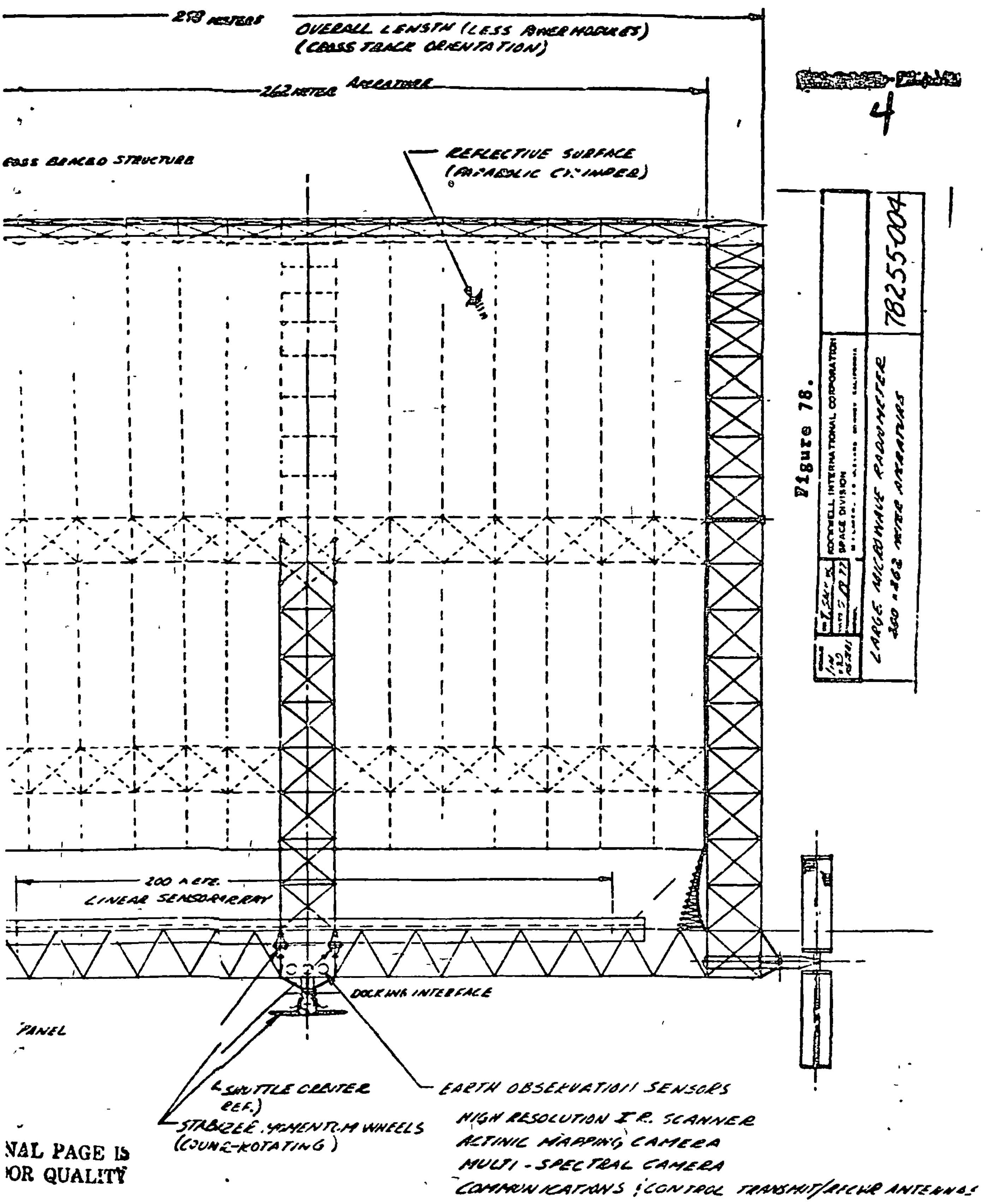

Figure 78.

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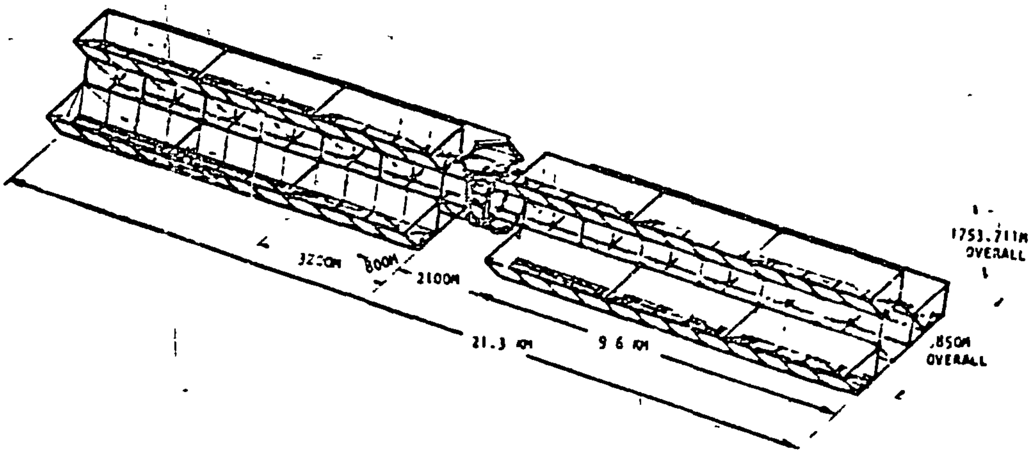

Figure 79. Photovoltaic Point Design Concept

Table 5. Photovoltaic Point Design Characteristics

OVERALL DESCRIPTION

- 5-GW POWER TO UTILITY INTERFACE
- GEOSYNCHRONOUS CONSTRUCTION LOCATION
- SINGLE MICROWAVE ANTENNA
- GEOSYNCHRONOUS EQUATORIAL OPERATIONAL ORBIT

SUBSYSTEMS

POWER CONVERSION
- GaAlAs SOLAR CELLS
- CONCENTRATION RATIO = 2

ATTITUDE CONTROL/STATIONKEEPING
- Y-POP, X-IOP
- ARGON ION THRUSTERS

POWER DISTRIBUTION
- 45.5 KV DC
- STRUCTURE/WIRING NOT INTEGRATED

MICROWAVE ANTENNA
- GAUSSIAN BEAM
- 2.45-GHz FREQUENCY
- ELECTRIC PHASE CONTROL
- RCR WAVEGUIDE PANELS
- TENSION-WEB, COMPRESSION FRAME STRUCTURE

STRUCTURE
- ALUMINUM (GRAPHITE/THERMAL PLASTIC ALTERNATE AS NEEDED)
- BEAM MACHINE CONSTRUCTION

INFORMATION MANAGEMENT
- DISTRIBUTED

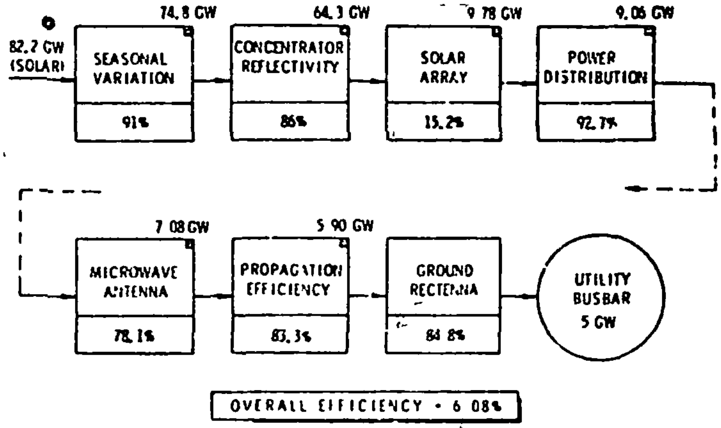

Figure 80. Photovoltaic Point Design End-Of-Life Efficiency Chain

Table 6. Photovoltaic Point design Mass Statement

SUBSYSTEM	WEIGHT (MILLION KG)
COLLECTOR ARRAY	
STRUCTURES AND MECHANISMS	3.777
POWER SOURCE	8.830
POWER DISTRIBUTION & CONTROL	1.166
ATTITUDE CONTROL	0.095
INFORMATION MANAGEMENT & CONTROL	0.049
TOTAL ARRAY (DRY)	(13.917)
ANTENNA SECTION	
STRUCTURE AND MECHANISMS	1.685
THERMAL CONTROL	1.408
MICROWAVE POWER	7.012
POWER DISTRIBUTION & CONTROL	3.438
INFORMATION MANAGEMENT & CONTROL	0.630
TOTAL ANTENNA SECTION (DRY)	(14.167)
TOTAL SPS DRY WEIGHT	28.084
GROWTH (30%)	8.425
TOTAL SPS DRY WEIGHT WITH GROWTH	36.509
PROPELLANT PER YEAR	0.040

Energy Conversion

Figure 81 shows the configuration of the SPS point design solar array wing structure. The concept is a three-trough, two-tier system. The structure is made up of tri-beam girders whose longitudinal members and transverse struts are fabricated on orbit by a beam machine. Shear stabilization of the tri-beam girders and the wing itself is achieved by the use of X-tension cables. Current structure material is structural aluminum. Excessive stresses and/or deflections could drive the material selection to the regime of composites. The dimensions indicated have been verified to be adequate when the vehicle is subjected to a worst-case forces and torques environment in geosynchronous orbit in that they result in an acceptable margin of safety for a basic material thickness of 0.254 mm (0.010 in.), which is considered minimum gauge.

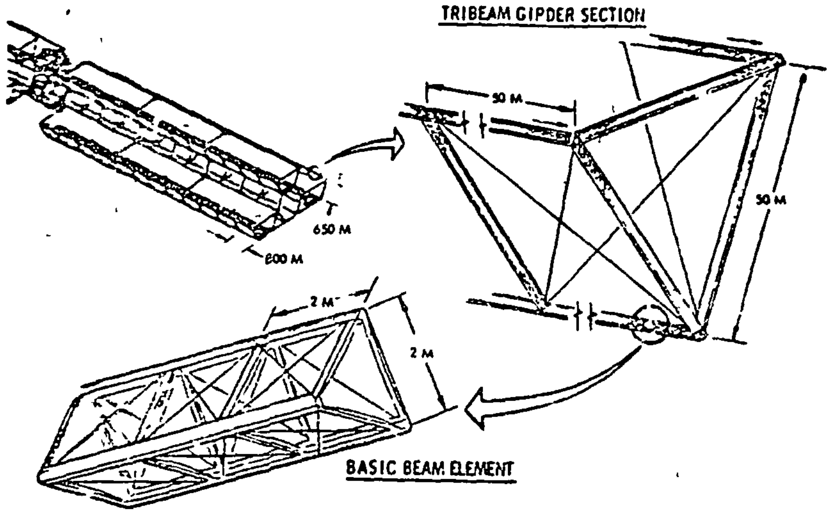

Figure 81. Photovoltaic Wing Structure

Figure 82 shows the solar array blanket description and array characteristics. The point design utilizes a GaAlAs solar cell efficiency of 20-percent AMO, 28°C, and the sizing of the array is based on 125°C operating temperature (17.6% cell efficiency). The total output of the array is 9.92 GW with a voltage output of 45.5 kW for each array panel. The solar blanket weight is 7.65×10^6 kg, and the total array weight (including the concentrator) is 8.83×10^7 kg. This weight is based on a specific weight for the blanket of 0.25 kg/m^2 and 61.2×10^6 m^2 cell area. A cross-section of the solar cell is also shown (Figure 82). The 20-μm synthetic sapphire (Al_2O_3) substrate, used in an inverse orientation, also acts as the cell cover. The reflectors are composed of 12.5-μm aluminized kapton.

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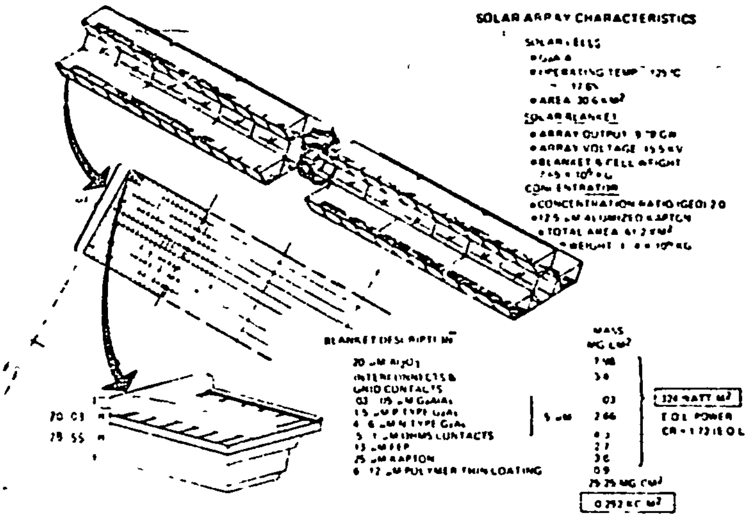


Figure 82. Photovoltaic Energy Conversion System

Power Distribution

A flow diagram of the overall power distribution subsystem is presented in Figure 83. Power obtained at the subarray is transferred to a summing bus through a switch gear (SG) and manually operated circuit-breaker. Power is then transferred from the nonrotating member to the rotating member of the rotary joint through slip rings and brushes. On the rotating member, power is conducted through switch gears to dc/dc converters which output the six primary voltages required by the klystrons. Each voltage is conducted to a summing bus through a switch gear. Subsequently, each voltage is conducted from the summing buses to the 135,864 klystrons.

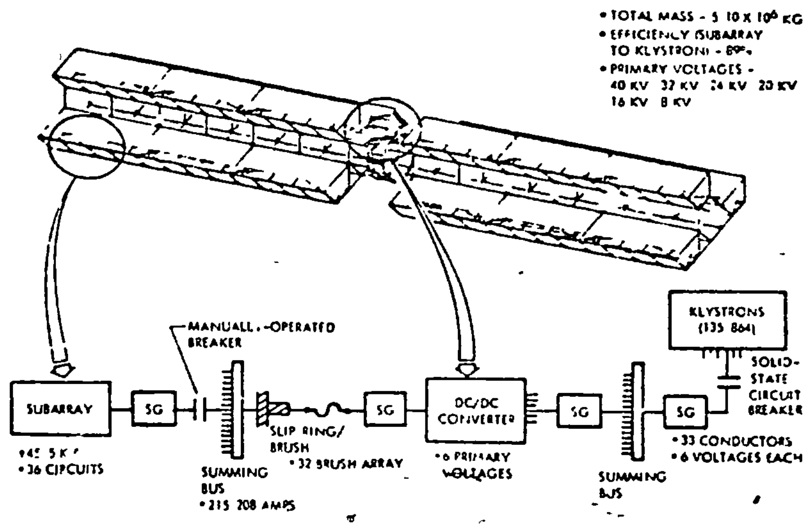
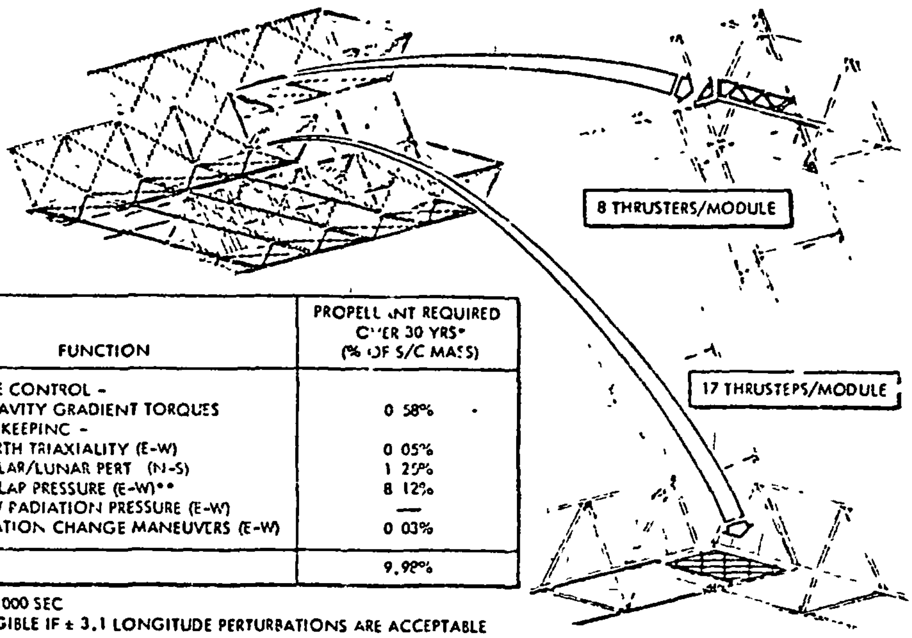


Figure 83. Photovoltaic Power Distribution Subsystem

Attitude Control and Stationkeeping

Trade studies indicated the desirability of a simple ACSS employing high-performance electric thrusters, and use of the Y-POP, X-IOP orientation and inertia balancing to minimize attitude control propellants. Figure 84 shows such a system employing eight RCS quads, two on each corner of the spacecraft. The total RCS propellant requirements (see table) are low, due primarily to the high specific impulse (13,000 s) which is believed to be feasible with the argon ion bombardment thrusters.



FUNCTION	PROPELLANT REQUIRED OVER 30 YRS* (% OF S/C MASS)
ATTITUDE CONTROL -	
• GRAVITY GRADIENT TORQUES	0.58%
STATIONKEEPING -	
• EARTH TRIAXIALITY (E-W)	0.05%
• SOLAR/LUNAR PERT (N-S)	1.25%
• SOLAR PRESSURE (E-W)**	8.12%
• MW RADIATION PRESSURE (E-W)	—
• STATION CHANGE MANEUVERS (E-W)	0.03%
TOTAL	9.98%

*I_{sp} = 13,000 SEC
** NEGLIGIBLE IF ± 3.1 LONGITUDE PERTURBATIONS ARE ACCEPTABLE

Figure 84. Photovoltaic Attitude Control and Stationkeeping Subsystem

The dominant stationkeeping propellant requirement is the complete correction of the solar pressure perturbation. This requirement can be eliminated if a ±3.1-degree longitude stationkeeping accuracy is acceptable. The present stationkeeping accuracy goal is 0.5 degree. An effort is currently underway to define a solar pressure correction policy which meets the 0.5-degree accuracy requirement, but will reduce the propellant requirement.

The ACSS attitude reference determination system features charge-coupled device (CCD) star and sun sensors as well as electrostatic or laser gyros and dedicated microprocessors. Five attitude reference determination units are at various locations on the spacecraft to sense thermal and dynamic body bending and to desensitize the system to these disturbances. The control algorithms will feature statistical estimators for determining principal axis orientation, body-bending state observers or estimators, and a quasi-linear RCS thrust command policy to provide precise control and minimize structural bending excitation. The ACSS hardware mass is very small relative to the 30-year propellant requirement.

Satellite Antenna

The basic satellite antenna configuration is shown in Figure 85. Three main components comprise the structure—a tension web made from composite wires or tapes, a catenary cable that transfers the web tension to the vertices of the third component which is a hexagonal compression frame. Original analyses of this structure assumed an allowable midspan web deflection of only 0.75 cm. As a result, the structure weight was comparable with other concepts such as the rigid matrix system. Recent work in the microwave subsystem area indicates that midspan deflections of approximately one meter are acceptable with the resulting misalignment being compensated by electronic beam steering.

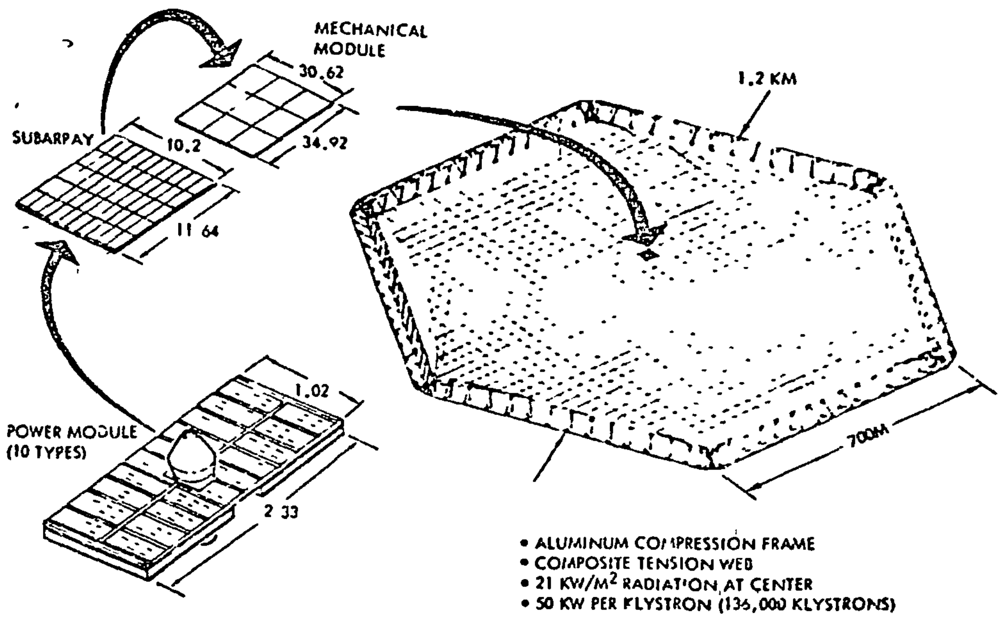


Figure 85. Satellite Antenna

The smallest antenna building block is the power module, which varies in size from the one illustrated (which is used at the center portion of the antenna) to 3.40 by 5.82 meters at the periphery of the antenna. Ten different power module sizes are used to comprise the antenna. Each power module has a klystron located in its center. The power modules are arranged into subarrays measuring 10.2 by 11.64 meters. Each subarray has its own phase control electronics. Nine subarrays are connected to form a mechanical module 30.62 by 34.92 meters. The mechanical modules are attached to the tension webs.

Rectenna Concept

Each rectenna is designed to accept power from a single satellite and provide 5 GW of power to the utility interface. As shown in Figure 86, a typical rectenna site located at 34°N latitude covers an elliptical area 13 km in the north-south direction by 10 km in the east-west direction. This area contains 814 rows of rectenna panels tilted 40 degrees from the horizontal, providing an active intercept area of 78.54 km^2.

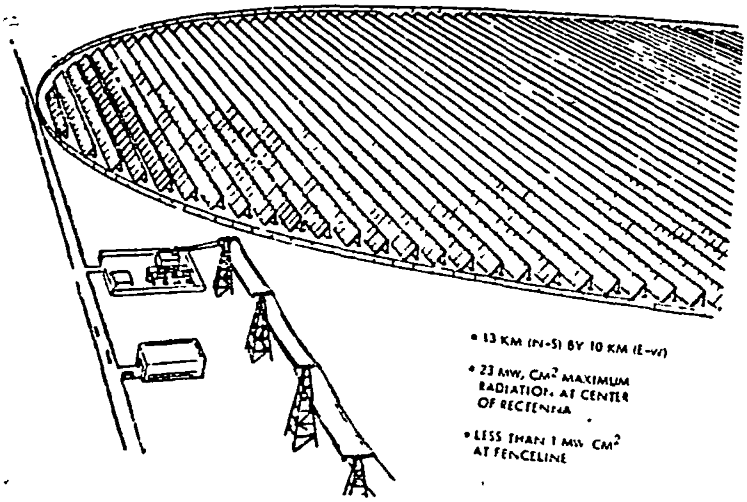


Figure 86. Rectenna Site

SPS Construction

The entire satellite is constructed in geosynchronous orbit. Construction equipment and materials are transported from LEO to GEO on a solar-electric propulsion vehicle previously described. Men are transported between LEO and GEO on a two-stage LH_2/LO_2 rocket-propelled vehicle.

The sequence and schedule for satellite construction are shown in Figure 87. A single integrated construction facility builds the structure and installs the solar blankets, reflectors, power distribution system, and other subsystem elements located in the wings. Construction starts with one wing tip and progresses toward the center section where the rotating joint for the microwave antenna will be located. Construction then continues outbound, building wing number 2, and terminating at that wing tip.

The first eight days are designated for preparation of the construction facility. Prior to the eighth day, sufficient materials have been delivered to satisfy the first several days of consturction—primary structural material (beam machine cassettes) for half of the satellite; solar blanket and reflector rolls, electrical conductors, and switch gear for the first two bays; and microwave antenna components. Since the rear side of the facility is always exposed to space with no interference from the main construction activities, it is used as the jig for building the microwave antenna frame and as the location for assembly and installation of the 30×30-m microwave subsystem mechanical modules. Fabrication of the microwave antenna for this Nth satellite was started on the 50th day of construction of the previous (N-1) satellite and is continued up through the 48th day of construction of this satellite. At that time, it is ready for installation on the slip ring mounted trunions.

Each satellite wing consists of 12 bays which are 800 m long. These are constructed at the rate of one every two days using three 8-hour shifts per

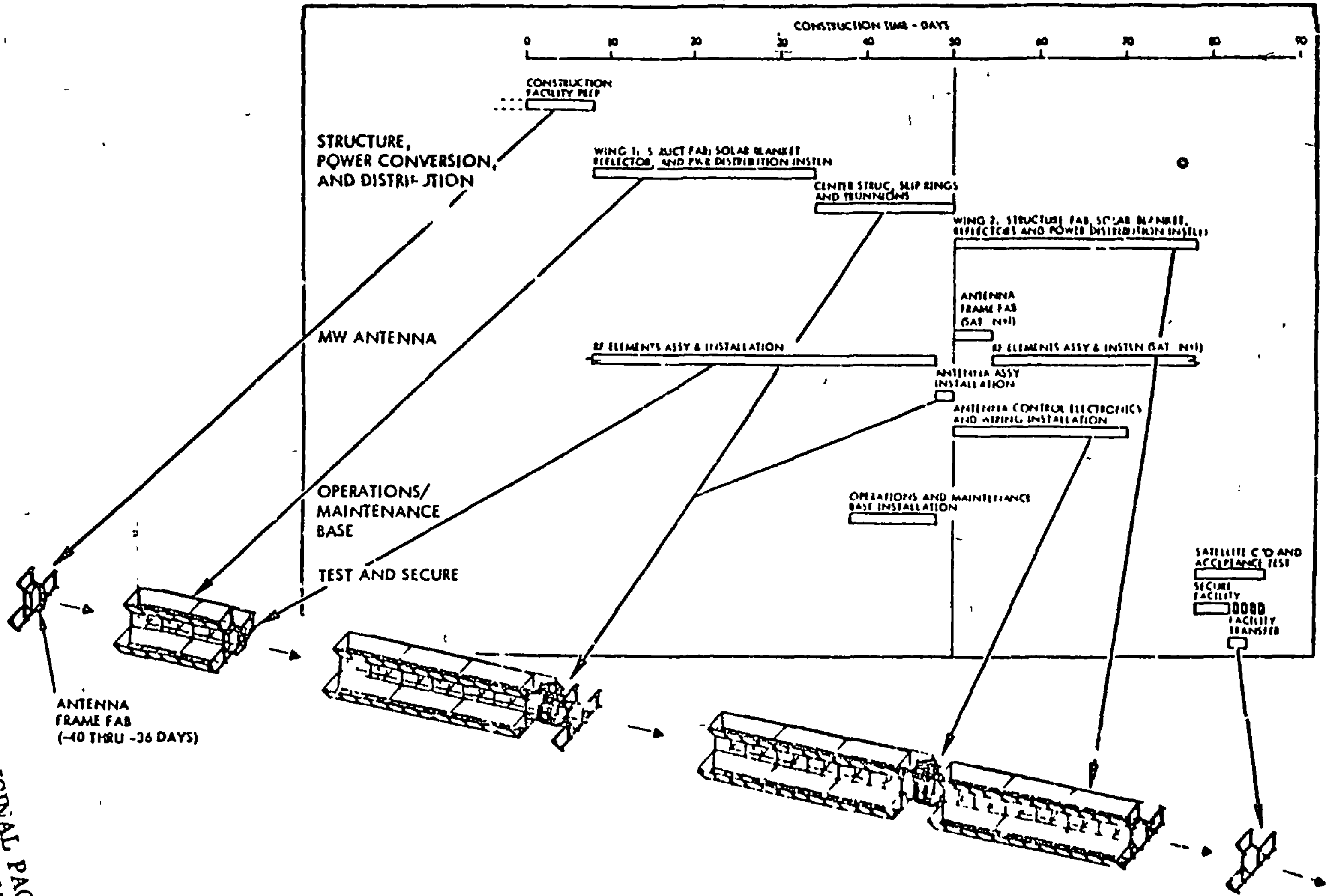


Figure 87. Nth Satellite Construction Sequence

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day. The structure and installation of the power conversion system of Wing 1 is completed on the 34th day. While Wing 1 construction is taking place, the microwave antenna crews are proceeding with the assembly, test, and installation of the antenna elements into the antenna frame. The antenna assembly continues during the construction of the center station.

Subsequent to completion of Wing 1, the construction facility constructs the longerons and frames in the center section, installs the slip rings, constructs the tension supports, installs the trunions, and installs power wiring in the center. Although 16 days are scheduled for this activity, the timeline requires only 12 days with two additional days scheduled for transfer of the antenna to the trunion mounts. Two days are allowed for contingencies.

Immediately upon completion of the center section primary structure, the facilities for the operation and maintenance base are installed and the first operational maintenance crew arrives to support installation of the antenna control electronics and satellite checkout, which takes place from Day 50 through Day 69.

By the 51st day, all satellite hardware has been delivered. On-site logistics activities are therefore greatly reduced, freeing construction support personnel for subsystems hookup and checkout during the Wing 2 construction period.

Use of the construction facility is completed on Day 78, and flyaway transfer to the construction site of the next satellite occurs on Day 84. Final satellite checkout and acceptance testing is completed on Day 86.

Figure 88 shows a perspective view of the tribeam construction facility. The facility is configured to restrain the free end of each cross-frame member as it is fabricated. After completion of each 800 m of longitudinal members, the construction facility is stopped, the cross-frame complexes are translated to their offset positions, and the cross-frame members are completed and joined to the longitudinals.

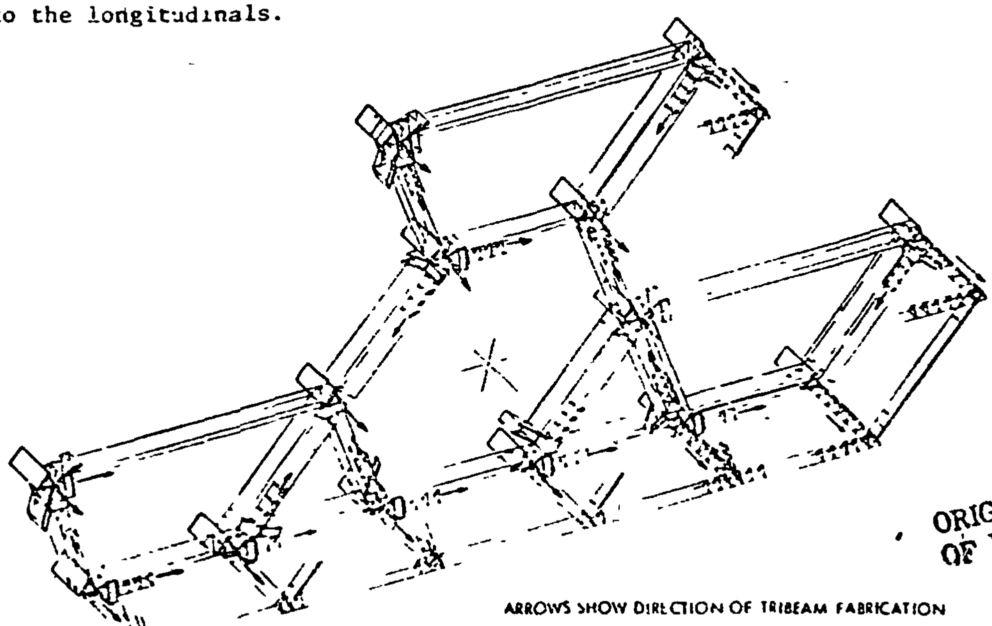

Figure 88. Satellite Tribeam Construction Jig

Orbital Base Concepts

Three orbital bases have been identified to support satellite construction, satellite operations and maintenance, and low earth orbit logistics. These concepts are described below.

Satellite Construction Base

Construction of the satellites takes place in GEO at its designated operational longitude. The concept for the GEO construction base is illustrated in Figure 89. Construction is accomplished almost entirely from the single assembly and fabrication fixture shown in the left side of the figure. A crew size of 640 has been established for accomplishing the construction in the scheduled time. The crew and their facilities are divided equally and are located on each side of the hexagon portion of the fixture. One of these 320-men bases, shown in the figure, consists of 7 three-module crew habitability complexes plus two base management modules, two pressurized storage modules, and solar array power modules.

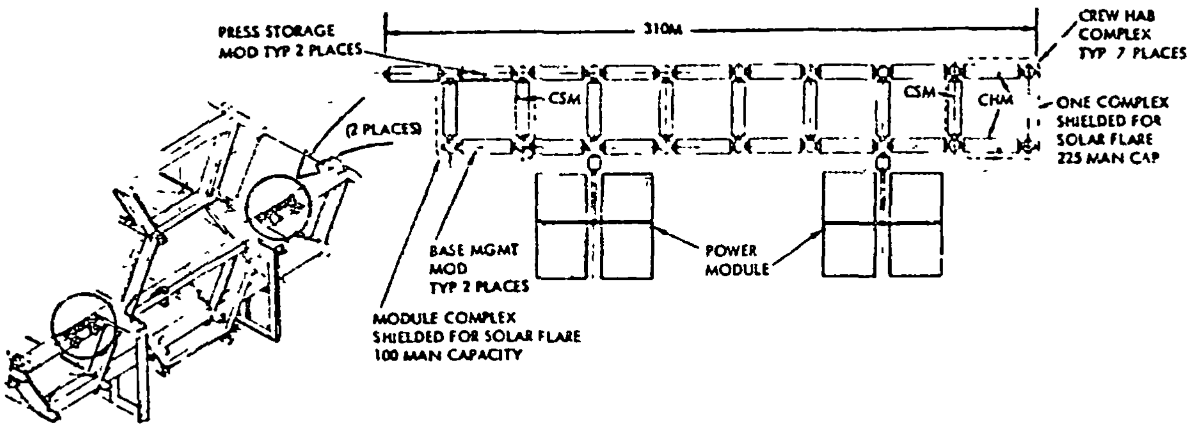

Figure 89. Geosynchronous Orbit Construction Base (Crew Size: 640)

The modules of the crew habitability complex are described in more detail later (Figure 91). Each complex is composed of two crew habitability modules, each of which provides staterooms, personal hygiene facilities, and support subsystems for 24 crew members; and one crew support module which provides galley, recreational and medical facilities, and subsystems for the 48 crew members of the two crew habitability modules. Base management modules house the communications and control systems for the base and the construction facility. The pressurized storage modules include workshops for maintenance of construction facility elements and satellite hardware as required.

Seven of the modules (indicated by the dashed lines) are hardened against solar flare radiation and serve as temporary quarters for the entire crew when the base is subjected to that environment.

Operations and Maintenance Base

Figure 90 shows the permanent operations and maintenance base which is installed on each satellite prior to completion of construction. This base is located near the center of the satellite for best access to all parts of the satellite, and is installed subsequent to completion of the center structure as described in the discussion of the construction schedule. A maintenance crew of 20 has been estimated. The functions of the five modules which comprise the base are identified in the figure. The crew habitability module internal configuration is the same as for the construction base. The crew support module also has the same internal functions as the construction base, but occupies only half of the module, the other half being an integrated multi-crew member EVA preparation and airlock station.

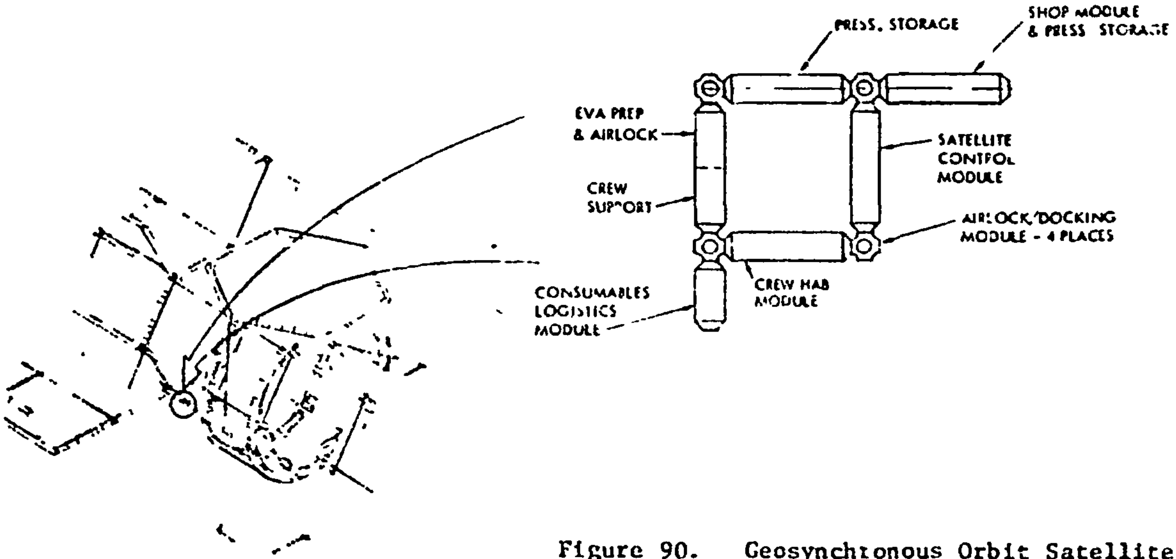

Figure 90. Geosynchronous Orbit Satellite Operations and Maintenance Base (Crew Size: 20)

Low Earth Orbit Base

The LEO base personnel provide supervisory activities for transfer of up and down payloads between the HLLV and the OTV's and perform the scheduled maintenance required by the COTV (changeout of thruster screens). Figure 91 illustrates the concept for this base. It has one crew habitability module and one crew support module of the same configurations as the GEO construction base, except that six of the 30 staterooms are located in the crew support module. Direct transfer of crew and equipment between the HLLV and the OTV's is planned; however, multiple docking ports and excess subsystems capacity and power are provided for emergency staging support.

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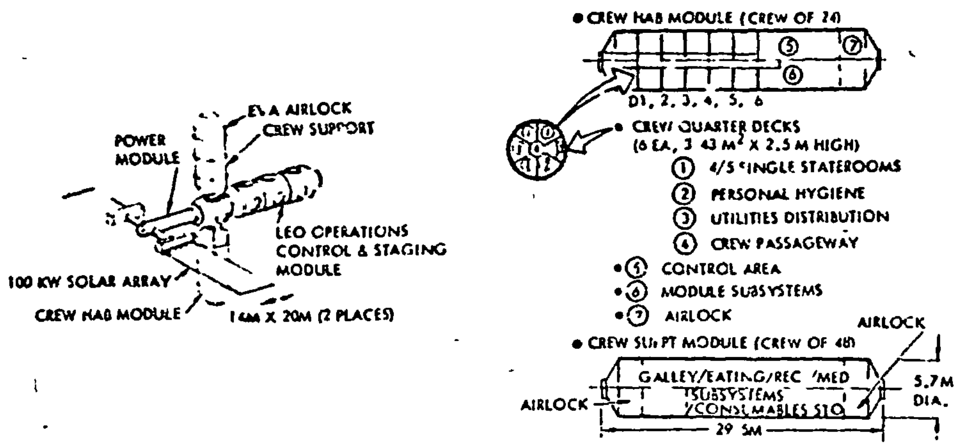


Figure 91. Low Earth Orbit Base (Crew Size: 30)

Mass Flow to Orbit

Satellite mass flow requirements, categorized by major subsystems to support the construction schedule of one satellite, is shown in Figure 92. The initial mass requirement can be accommodated on one COTV and would be scheduled to arrive at the GEO site during the construction facility preparation, which occurs during the eight days prior to commencement of satellite construction. The schedule requires that all material be delivered in 72 days. However, it is planned to construct the antenna frame and commence installation of antenna components for the next SPS during the latter part of the construction schedule. Material delivery to support this construction is shown on the microwave antenna and rotary joint line, which extends past the 72 days.

A total of 409 HLLV flights is required to transport 37.2x10⁶ kg, representing the mass of one SPS, to LEO. Ten different payload mixes, averaging 91,000 kg each, have been defined and sequenced to support construction needs. An HLLV launch schedule of eight flights per day has been postulated and is shown as the top line of the figure. The schedule is within the projected launch rate capability, considering other requirements such as maintenance material and crews. This results in total SPS mass delivery in 51 days—21 days ahead of the required completion—thus providing considerable margin for contingencies which could slow delivery rate.

An analysis of cargo packaging was conducted to assure that the construction materials can be properly packaged in quantities consistent with construction requirements and in packages that fully utilize the payload weight capability of the HLLV, while not exceeding the volume constraints. Table 7 illustrates packaging concepts for major elements of the satellite. These package configurations, sizes, and specified quantities per satellite are designed for compatibility with the satellite construction concept and construction equipment described earlier.

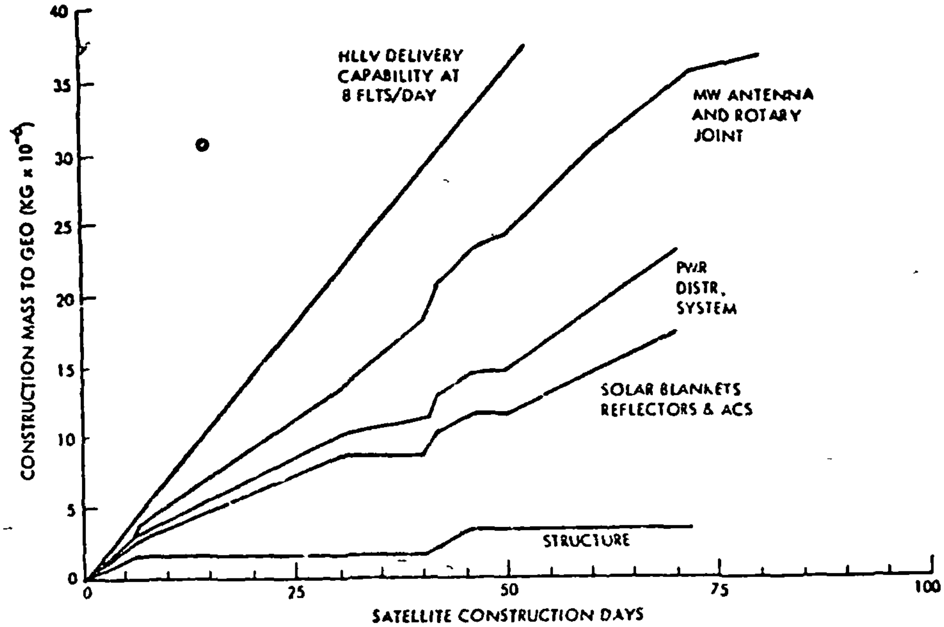
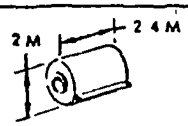
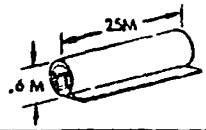
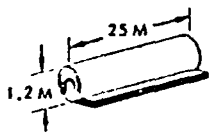
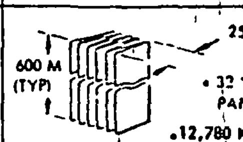
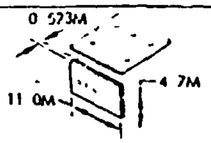


Figure 92. Mass Flow Demands for Satellite Construction

Table 7. Cargo Packaging

SPS ELEMENT	PACKAGING	PACKAGE DIMENSIONS	NO REQUIRED	NOTES
STRUCTURES	CASSETTES OF ALUMINUM TAPES		1188	6 DIFFERENT TAPE LENGTHS 2500 KG AVE MASS
SOLAR BLANKETS	ROLLS		1632	750 M LENGTH/ROLL 7136 KG/ROLL
REFLECTORS	ROLLS OF FABRIC-HINGED ALUMINIZED KAPTON SHEET		144	 • 32 "HINGED" PANELS • 12,780 KG/ROLL
MW ANTENNA WAVEGUIDE PANELS	SUB ARRAYS		6993	• ALL SUBARRAYS HAVE SAME OVERALL DIMENSIONS • 10 DIFFERENT POWER MODULE SIZES - QUANTITY VARIES WITH SIZE • SUBARRAY MASS (AVE) = 716 KG

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The primary structure cassettes simultaneously feed each beam machine to produce the basic 2-m triangular beam elements used in construction of the 50-m girders. All cassettes contain sufficient material to complete half of the satellite structure, thus requiring replacement only once during satellite construction.

Each solar blanket roll is 750 m long—the length required for one bay. For a 500-m-wide bay, 22 of these 25-m-wide rolls are mounted side by side in the blanket layer and deployed simultaneously. End and side attachment materials and hardware are packaged separately.

The reflectors are 600 m wide and 800 m long per panel when deployed. When packaged, the reflectors have an accordian-fold 25 m wide. The resulting 25×600-m strip is then rolled for packaging as shown.

The 6993 waveguide panels are the lowest density payload item and, therefore, become a major driver in packaging and scheduling payloads. Based on the average shipping dimensions and mass for each panel given on the table, a maximum of 22 panels for a total mass of 15,750 kg can be carried in the HLLV cargo bay.

In addition, klystrons (which do not present a packaging problem) are a major payload item. The microwave antenna contains a large number of subarrays that, in turn, are composed of up to 50 power modules. Each power module has a klystron which is shipped to GEO separately and inserted after the subarray has been secured to the antenna. Each klystron has an average volume of 0.092 m^3 and weighs 45 kg; 135,864 are required for each satellite.

Propellant Production

For each kilogram of mass to orbit, 16 kg of propellant are needed for the HLLV, assuming the use of a horizontal-takeoff, single-stage-to-orbit concept. Of this propellant, the mass ratio of oxygen to hydrogen is 1.7:1. Although oxygen comprises the greatest mass, production of hydrogen presents the greatest problem.

Several processes were considered for the production of hydrogen. Of these, coal gasification and electrolysis of water appeared to warrant in-depth analysis. These processes were analyzed to assess relative production costs and, for coal gasification, the method of transport of coal or hydrogen to the launch site. It is assumed that electrolysis can be accomplished in the launch site area, negating the need for long-distance transportation.

The major results of this evaluation are presented below in Figure 93 and Table 8. Figure 93 compares the costs of liquid hydrogen delivered at the launch site. Little difference in cost exists between producing the hydrogen at the coal mining site and shipping hydrogen to the launch site versus shipping coal (as slurry or on a train) to the launch site and producing hydrogen at the launch site. Electrolysis costs (assuming 10-mil/kW-h) are about twice the cost of coal gasification. As shown in Table 8, electrolysis has other advantages, of which environmental considerations are most important.

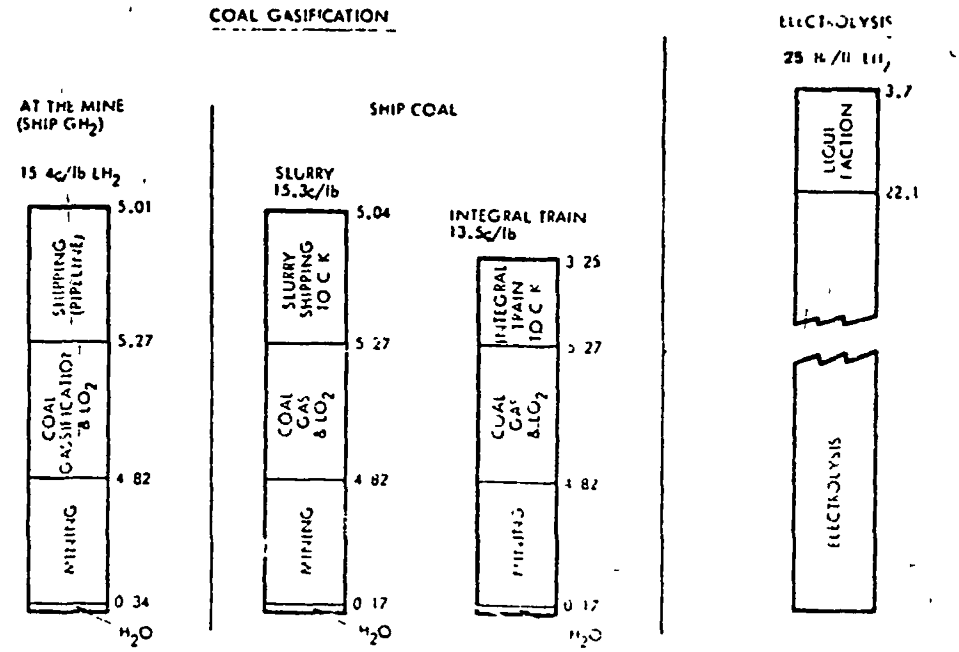

Figure 93. Preliminary Propellant Production Cost Comparisons

These data need to be incorporated into an economic assessment to determine impacts on total transportation costs. The synergism of the SPS concept and electrolysis would appear appealing if the overall cost impacts are not significant.

Table 8. Comparative Summary

	POSTIVE FACTORS FOR:	
	COAL GASIFICATION	SPS ELECTROLYSIS
• ENERGY REQUIRED	X	
• COSTS	X	
• ENVIRONMENTAL CONSIDERATIONS		X
• TRANSPORTATION REQUIREMENTS		X
• HYDROGEN ECONOMY		X
• MULTI-PURPOSE FACILITY		X

Rectenna Construction

Major elements of a 5-GW rectenna site located at approximately 34°N latitude are depicted in Figure 94. In order to minimize electrical wiring from the rectenna panels, two electrical switchyards are employed, each with its own converter and relay building. A rail spur line would be utilized, predominantly for the construction phase, to bring in gravel for the access roads and concrete plants and transformers for the switchyards. The four concrete plants would be removed after serving their function. The rectenna farm of 10×13 km contains 814 rows of rectenna panels tilted 40 degrees from the horizontal, providing an active intercept area of 78.54 km^2. Since an individual panel is 12.24×14.69 m, some 436,805 panels have to be assembled on site and erected.

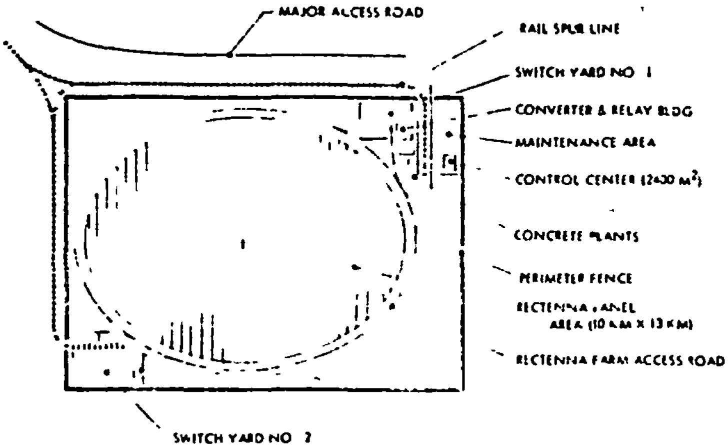

Figure 94. Rectenna Site Elements

Since the selected rectenna panel concept is comprised of solid sheets 1.35 cm thick, they are relatively insensitive to weather. However, because they are solid, high wind loads (up to 90 mph) must be considered in the construction of the support structure. Overall array deflections must be less than 3 cm. The support structure shown in Figure 95 employs preformed hat sections, standard I-beams, and 3.5-inch-diameter tube braces. The I-beams and braces support the structure on concrete piers.

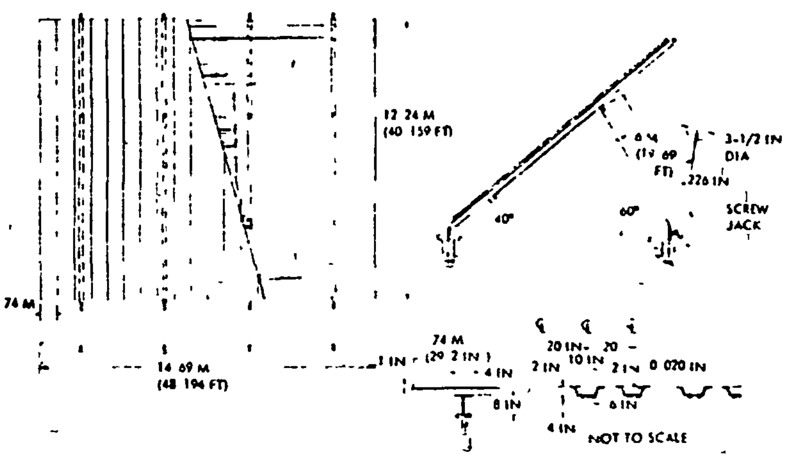

Figure 95. Rectenna Array Support Structure

Assembly of rectenna panels represents the major construction time challenge. The large numbers dictate the need for an assembly and erection concept like that shown in Figure 96. Fundamentally, the concept is a mobile assembly jig which, after having completed its share of the construction operations, can be disassembled and transported to another rectenna site. The assembly jig can be loaded to contain 10 sets of rectenna panel elements. Since each set weighs 2200 kg (~4800 lb), the 10 sets can be delivered to the jig on a single flat-bed truck. After the truck crane lifts off a completed rectenna panel (see insert) from their loaded locations at the side and end of the jig, the hat sections and I-beam tube braces are conveyed into place. Stops are used to assure

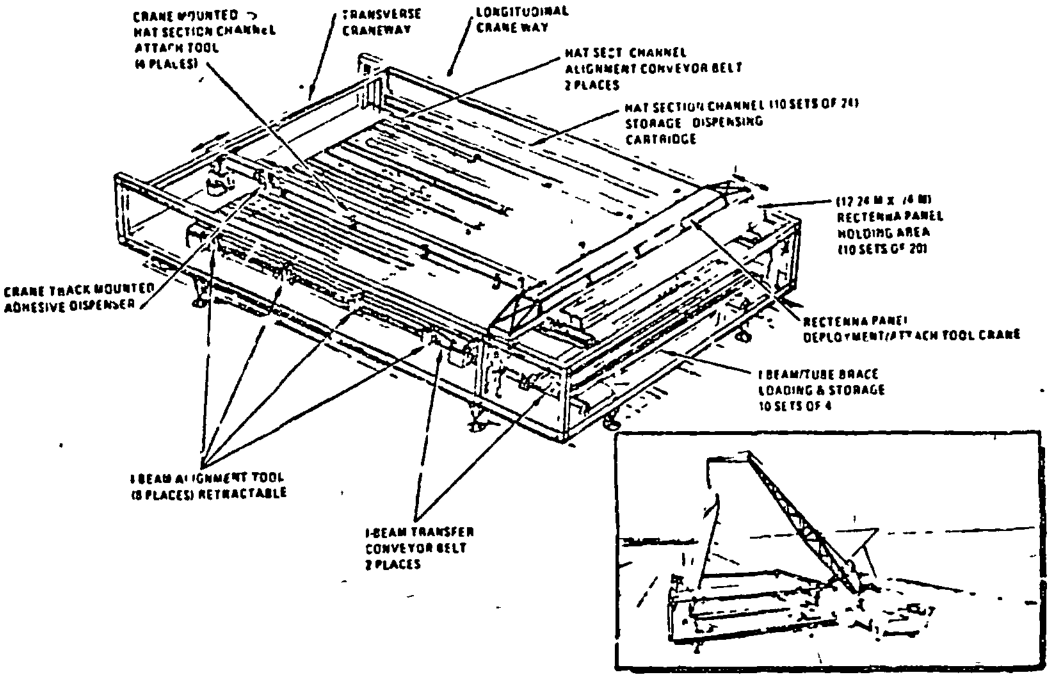

Figure 96. Rectenna Panel Assembly Concept

exact positioning and alignment. The manned truck-mounted crane unit then passes over the jig, securing the hat sections to the I-beams and laying down the adhesive for the rectenna panels. These operations consume approximately 21 minutes. Next, the rectenna panel crane moves longitudinally across the jig, placing each of the twenty 0.74-m-wide panels onto the completed structural frame. A geared eccentric roller on this crane provides the pressure to secure the rectenna panels to the frame. Wiring harnesses are then installed and the hoist sling is attached from the truck crane for removal of the completed unit. Ten array panels could be assembled in one eight-hour shift, but the number of assembly jigs is based on one assembly per hour. Installation of the completed panel on concrete piers is estimated to take about 20 minutes. One truck crane and installation crew should be able to work with two assembly jigs at a time.

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Impacts of rectenna siting alternatives on ease of integration into the power grid, power management, and cost have not yet been accomplished. This analysis requires an interaction between NASA and DOE activities. NASA must define the alternatives for rectenna locations, and DOE then must determine the impact of alternatives on the power grid. Three approaches to rectenna location that should bracket the possibilities are: (1) distributed, but near the load centers; (2) regional clusters; and (3) single location for all rectennas.

TRANSPORTATION ELEMENTS

A key element in overall feasibility of future space initiatives is the transportation concept(s), either available or projected to be available in the time frames being considered. Since transportation costs contribute significantly to the total cost of future *space industrialization*, methods of reducing transportation cost or simplifying transportation operations is mandatory. Primary drivers in establishing future transportation system requirements are the projected high mass flow and flow rates to low earth orbit (LEO) and geosynchronous earth orbit (GEO).

The Space Shuttle provides a new era of space transportation that will allow economical delivery and return of payloads from space during the early to mid 1980's. As new initiatives are started in the mid to late 1980's, Shuttle derivative configurations (SDV-1) with significantly increased annual cargo delivery capability (in excess of 6000 metric tons/year) will be available at a cost/kg to LEO of approximately 15 percent that of the Space Shuttle. In addition, solar electric propulsion (SEP) concepts will be available to more efficiently transfer larger cargo masses from LEO to GEO. By virtue of their higher propellant specific impulse, the total cargo mass requirement to LEO (primarily propellant) may be reduced by more than 50 percent of that required of a chemical system.

As we enter the 1990's and begin exploitation of the various space generated energy options, another evolution in space transportation systems will occur because of another quantum jump in orbital mass delivery requirements. A larger SEP system, with a payload delivery capability to GEO of up to 40 metric tons, will be required for transfer of solar power satellite (SPS) cargo. In addition, this SEP system may be employed as a proof-of-concept for the SPS.

In the late 1990's, a new earth launch vehicle concept will be required to support the construction of the first operational SPS. A preferred concept is a horizontal launch single-stage-to-orbit vehicle with a potential annual delivery capability to LEO of 600,000 metric tons at a cost of \$12 to 15/kg (1976 dollars). As we transition into the operational solar energy program, an even larger SEP system with a payload capability to GEO of up to 5000 metric tons will be required. This SEP transfer vehicle will further reduce the cargo mass to GEO by 80 percent of that required by a chemical OTV system.

A brief description of some of the major future transportation system elements are described in the following paragraphs.

Space Shuttle Derivatives (SDV-1)

Basically, the Shuttle derivative configuration replaces the Shuttle Orbiter with a cargo carrier capable of placing unmanned payloads of 84,000 kg in LEO, Figure 97. In addition, the Shuttle solid rocket booster (SRB) is replaced with lower operational cost recoverable liquid rocket boosters (LRB). The LRB's utilize derivatives of the Space Shuttle main engines (SSME). The derivative engine is a multi-mode engine which is capable of operation with LOX/RP and LOX/LH_2 to further reduce operational costs. The operational flow of the SDV-1 will be similar to that of the Shuttle transportation system. Because the vehicle is unmanned, a reduction in processing and launch preparation times may be expected. Minimum facility modifications will be required for servicing of the LRB in lieu of the SRB. The recoverable elements of the SDV-1 consist of the LRB's and a propulsion/avionics module. Recovery of the payload shroud is optional (i.e., no apparent cost advantage). A typical mission profile is depicted in Figure 98.

Since the SDV-1 is designed for cargo only, the Space Shuttle Orbiter will continue to provide the required personnel delivery to LEO. The derivative LRB's will also be used with the Shuttle Orbiter to provide a greater Orbiter payload delivery capability and reduced operational costs.

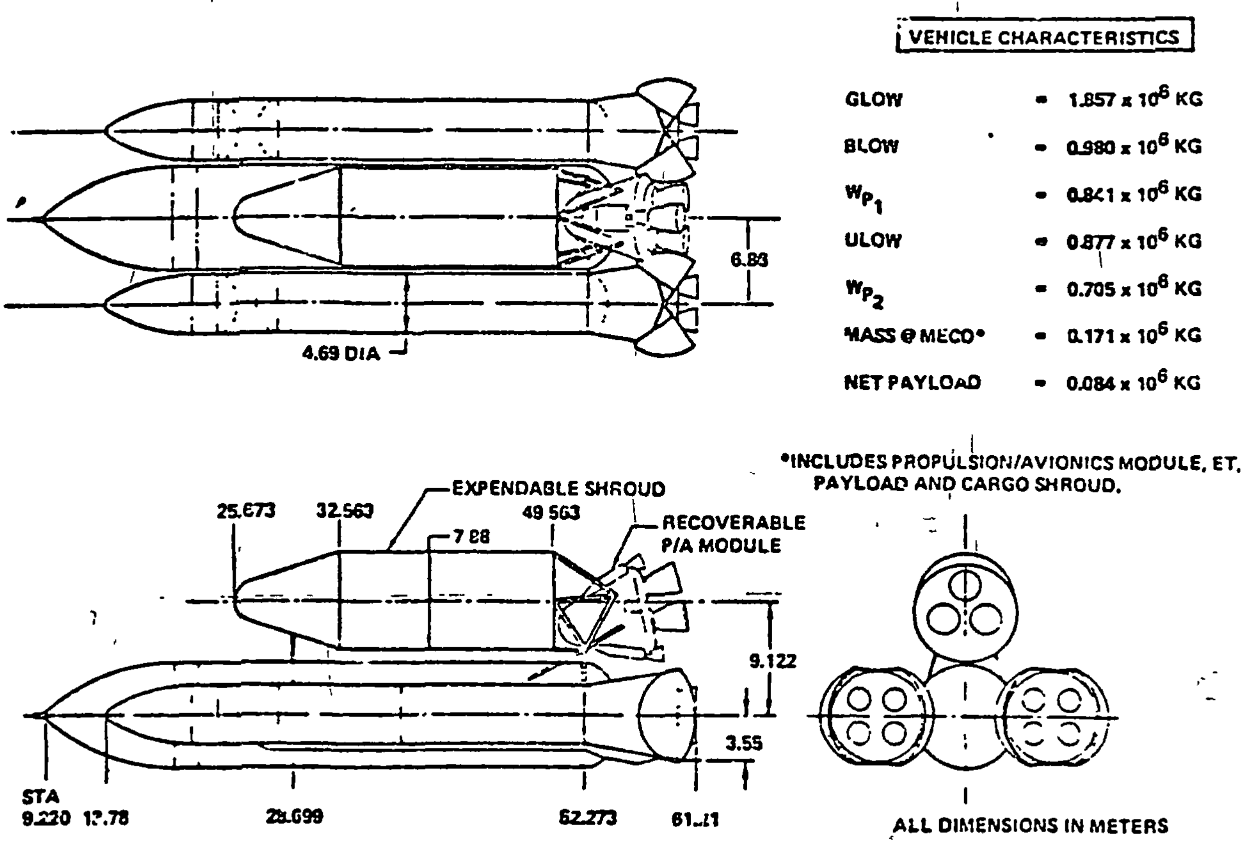

Figure 97. Space Shuttle Derivative SDV-1

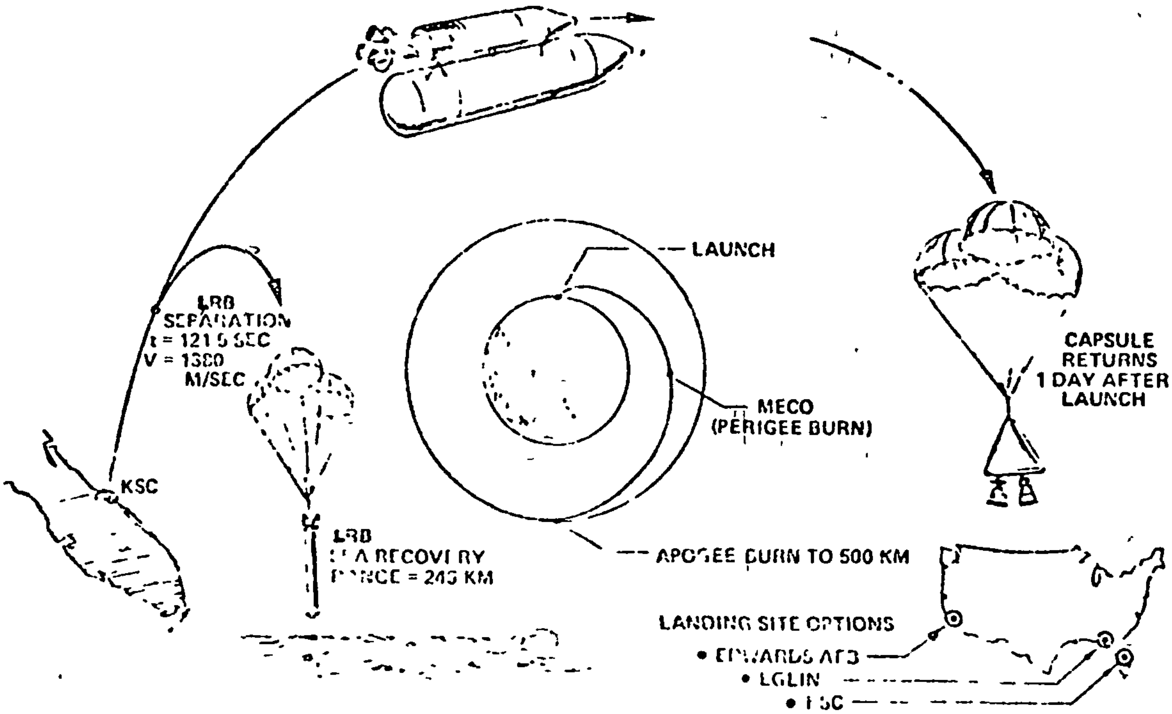

Figure 98. SDV-1 Mission Profile

Horizontal Takeoff Single-Stage-To-Orbit (HLLV)

The next generation earth launch vehicle will employ an airline transportation concept in order to minimize operational maintenance and turn-around times and overall operations cost. The need for vehicle stacking and staging, and recovery of booster stages at sea will be eliminated. The winged HLLV is designed to take-off and land on standard jet aircraft runways. The only unique facilities will be those required for cryogenic propellant servicing.

The single-stage-to-orbit configuration utilizes a wet-wing concept and multi-cycle airbreathing engines from takeoff to ~M = 7. Three SSME-type engines are employed from M = 6 to LEO. The vehicle has a cargo bay 6 x 6 x 30 m, and is capable of placing 91,000 kg in a 550-km equatorial orbit.

The winged booster, illustrated in Figure 99, is a tri-delta flying wing, consisting of a multi-cell pressure vessel of tapered, intersecting cones. The wing contour is a supercritical Whitcomb airfoil section with the leading edge modified to improve supersonic and hypersonic performance with essentially no reduction in subsonic performance. The outer panels of the wing and vent

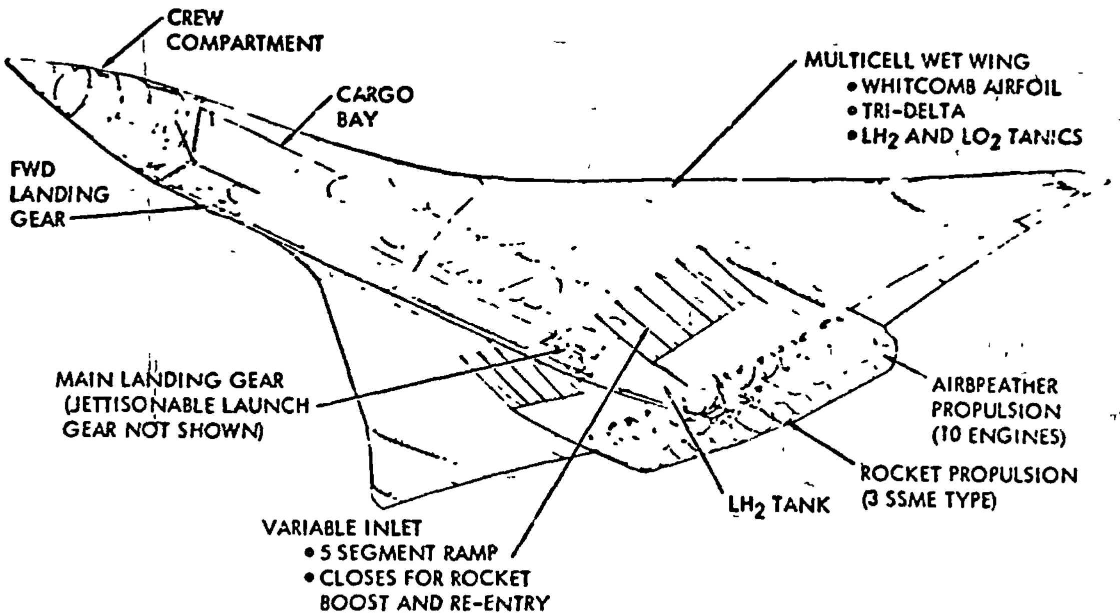

Figure 99. Winged HLLV - HTO/SSTO Concept

system lines in the wing leading edge provide the gaseous ullage space for the LH_2 fuel located in the inner two panels of the wing. LO_2 tanks are located in the wing about the c.g., over the five inboard airbreather engines in each wing panel.

In the aft end of the vehicle, three uprated SSME-type rocket engines (thrust = 1.8×10^6 lb) are connected to a two-cone LH_2 tank with a double-cone thrust structure. Approximately 50 percent of the volume of the vertical stabilizer is utilized as part of the gaseous ullage volume of the LH_2 tank.

The cargo bay is located forward of the LH_2 tank. The cargo bay floor is designed similar to the C5-A military transport aircraft; this permits the use of MATS and Airlog cargo loading and retention systems. The forward end of the cargo bay has a circular seal/docking provision to the forebody. Cargo is deployed in orbit by swinging the forebody to 90 or more degrees about a vertical axis at the side of the seal, and transferring cargo from the bay on telescoping rails. Recapture and reloading of the cargo in space is the reverse of that procedure. A size comparison of the winged HLLV and the C5A Galaxy is shown in Figure 100.

Ten high-bypass, supersonic-turbofan/airturbo exchanger/ramjet engines with a combined thrust of 1.4×10^6 lb are mounted under the wing. The inlets are protected by retractable ramps that close the inlets and fair the bottom surface into a smooth, continuous surface suitable for Sanger skip glider or high angle-of-attack ballistic reentry.

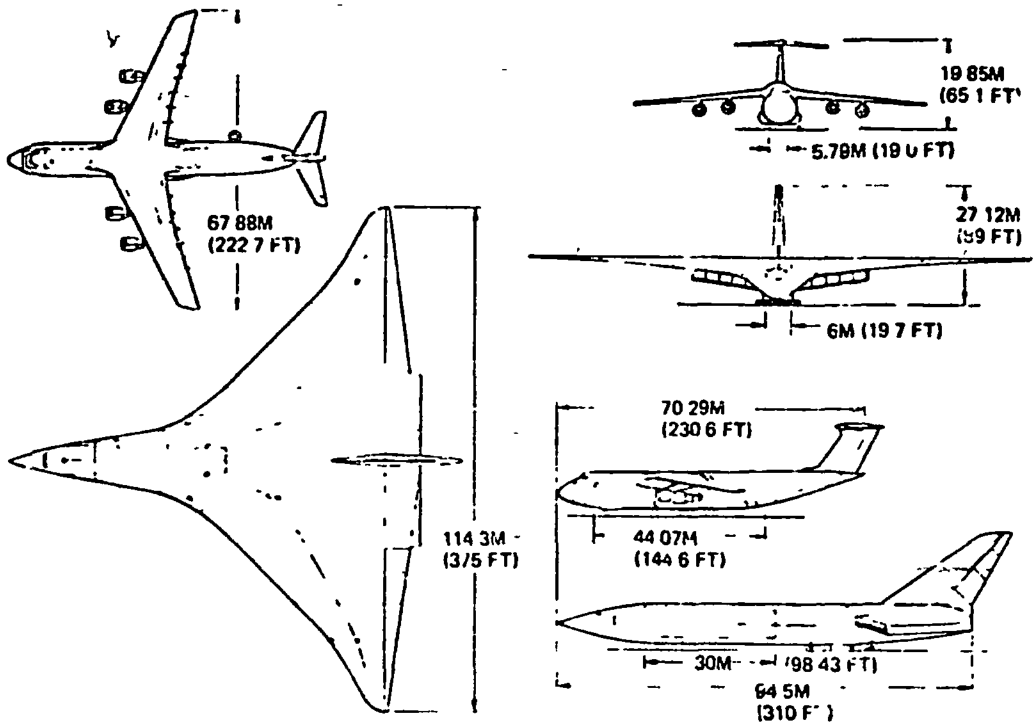

Figure 100. Winged HLLV - HTO/SSTO C-5A Galaxy

Unlike the ballistic HLLV, the winged vehicle is capable of cruise to the equatorial plane prior to injection into LEO. Therefore, there are 12 orbital rendezvous opportunities to a particular orbit with essentially a continuous launch window.

The winged booster trajectory is presented in Figure 101. Takeoff is accomplished under high bypass turbofan/air-turboexchanger power, with the ramjet acting as a supercharged afterburner. After clearing the runway, a launch gear truck is jettisoned and recovered by parachute. The vehicle then proceeds to climb to optimum cruise altitude and Mach number under turbofan power only. At cruise altitude, excess airbreathing engines are shut down to provide economical cruise to the equatorial plane. A large radius turn is executed into the equatorial plane, the idle airbreathing engines reignited, and a subsonic climb to a suitable altitude is accomplished under turbofan/air-turboexchanger power. A pitch-over into a constant energy, shallow-angle dive is than executed to accelerate through the high drag transonic region; after which, the vehicle will pitch up into a supersonic climb attitude — still under turbofan/air-turboexchanger power. At approximately Mach 3 and 85,000 feet altitude, the airbreathing engines transition to the ramjet mode and the turbojet shutoff vanes are closed to limit turbine machinery temperatures. The rocket engines are ignited at approximately 100,000 feet and 6200 ft/s, and burn in parallel with the ramjets. The ramjets are throttled down and the air induction system closed at Mach 7.2 and 130,000 feet. The

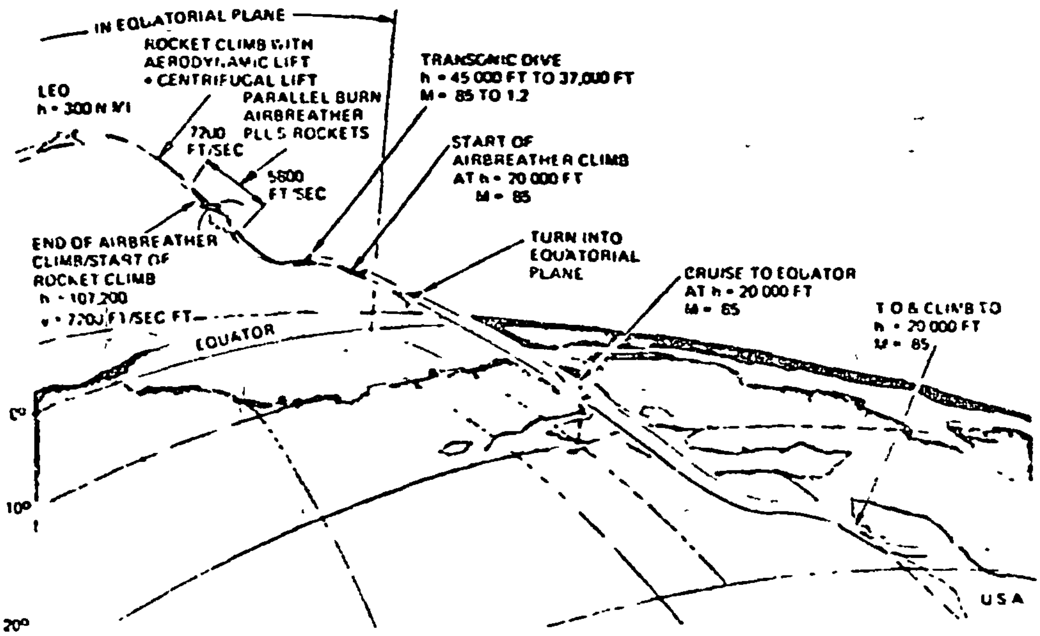

Figure 101. Winged HLLV - HTO/SSTO Trajectory

vehicle continues ascent to an elliptic equatorial orbit of 91 x 550 km after which the rocket engines are shutdown. A Hohmann transfer into circular orbit is then executed with the auxiliary propulsion system.

For reentry, the auxiliary propulsion system provides the ΔV required for deorbit. A low-flight-path-angle, high-angle-of-attack decleration maneuver is executed to approximately Mach 6. Partial plane changes are accomplished during this deceleration period. The angle of attack is then reduced to achieve maximum lift/drag for high-velocity glide to subsonic velocity. At approximately Mach 0.85, the inlets are opened and sufficient airbreathing engines are ignited for powered flight to the launch site and vehicle landing.

Chemical Orbital Transfer Vehicles

A family of chemical OTV's will be required for transfer of cargo and personnel from LEO to GEO for most proposed future space initiatives. These orbital transfer vehicles will be of the same basic design, but will vary in size to maintain compatibility with the earth launch vehicle concept in use at that particular time. A common-stage concept will be employed to simplify operational requirements and minimize cost.

The OTV configuration presented in Figure 102 is a mature version to be employed with the advanced winged HLLV configuration. The overall length, diameter, tank structures, and docking mechanisms are identical. The only

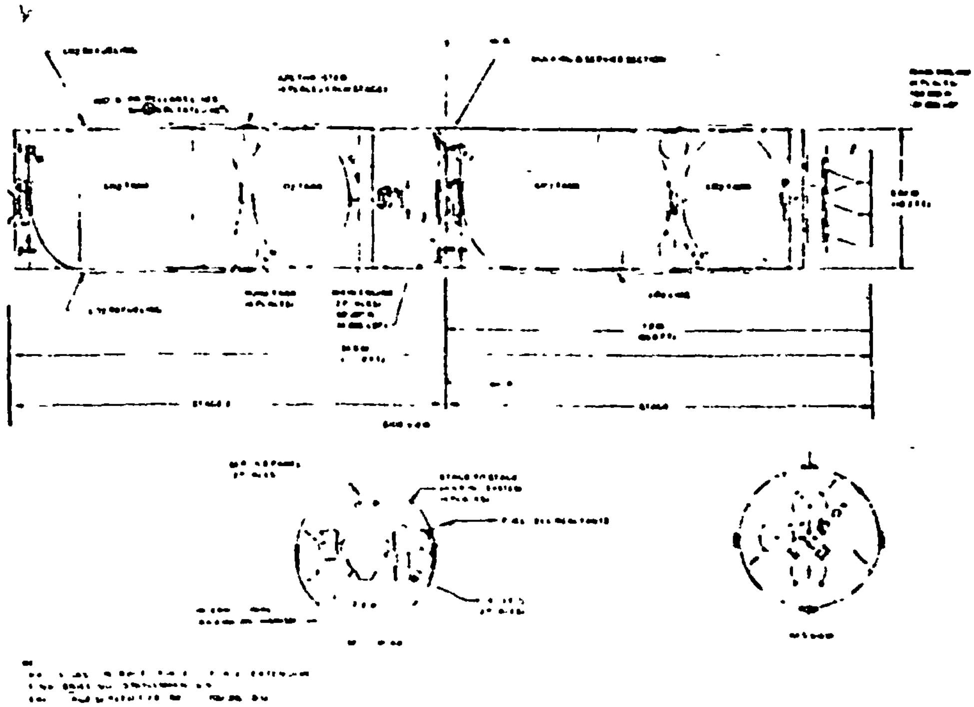

Figure 102. Common-Stage LO_2/LH_2 OTV Concept

significant difference in both stages are the number of engines — four for the first stage, and two for the second stage. This approach requires three winged HLLV flights to deliver a 91,000-kg payload to GEO (Figure 103). The first and second stages and payload module would be assembled on orbit. Following the LEO-GEO mission, the spent OTV stages would be recovered in LEO by subsequent winged-HLLV vehicles and returned to earth for refueling, refurbishment and reuse.

For personnel transfer, the same OTV would be employed with a crew and resupply module (CRM). A conceptual layout of the CRM is shown in Figure 104.

A command module area is required to monitor and control OTV performance during crew rotation flights. This function is incorporated in the forward section of the passenger module as shown. Spacing and layout of the passenger module is comparable to current commercial airline practice. A nominal packing density of 160 kg/m^3 (10 lb/ft^3) is assumed for resupply consumables. The resupply modules will be exchanged each mission. While at GEO, the resupply module could be used as the consumables storage module. Thus, multiple access aisles are also included in the sizing of the resupply module.

The logistics profile for a 48-man contingent at geosynchronous orbit for 90 days is presented in Table 9.

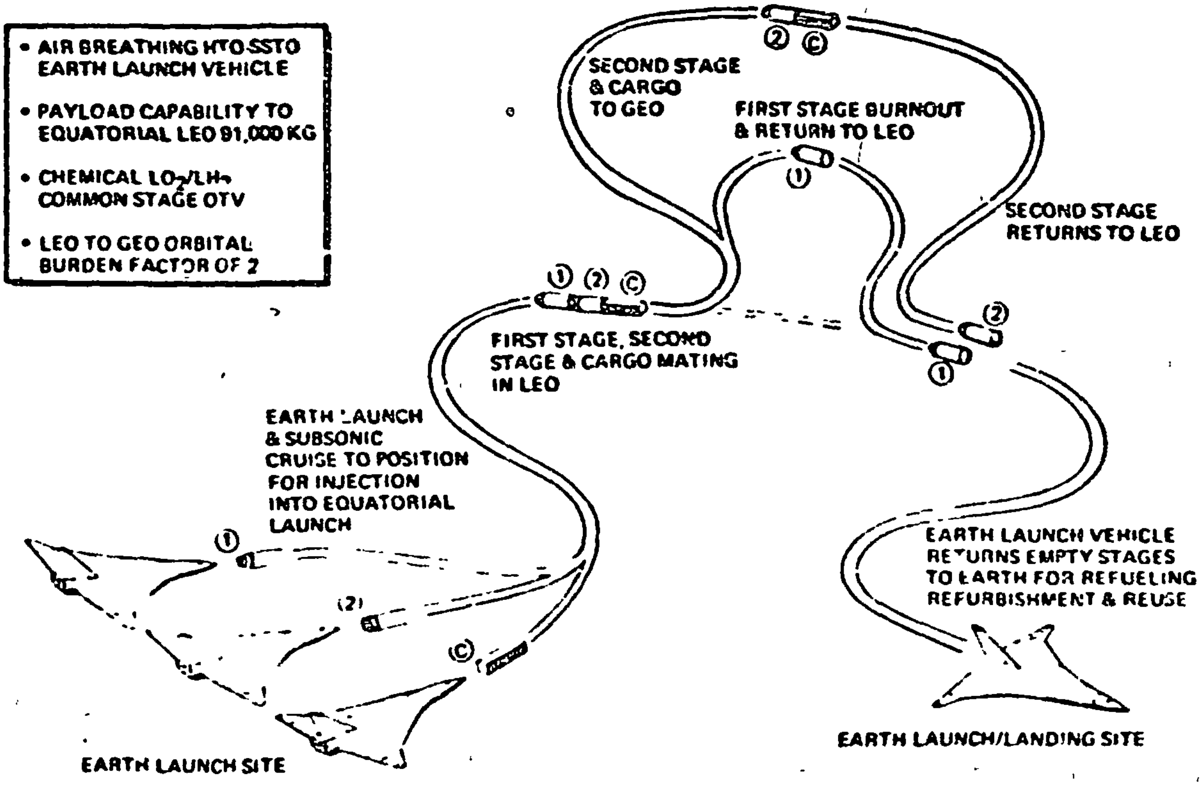

Figure 103. Orbital Transfer Vehicle Operations

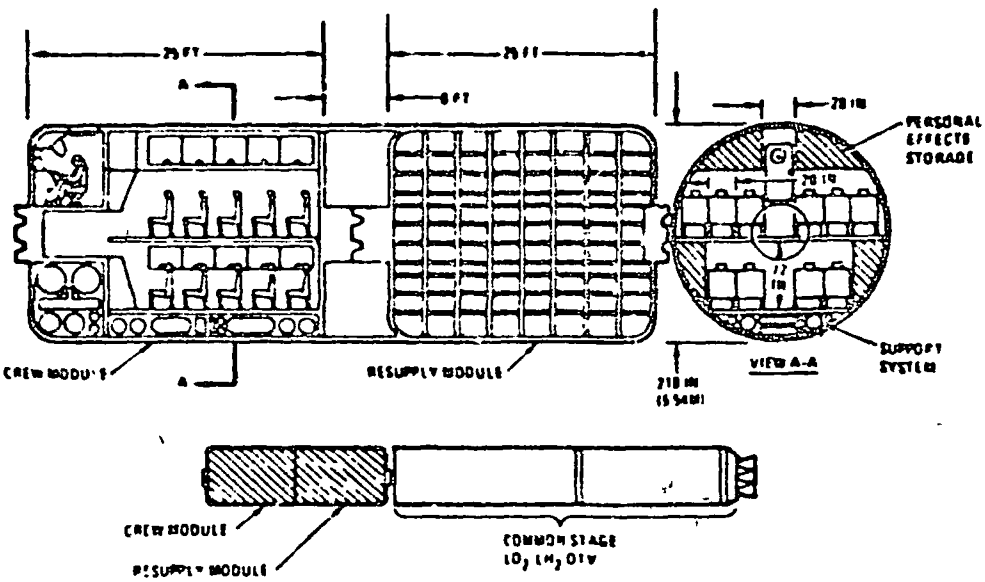

Figure 104. Crew and Resupply Module

Table 9. Crew Rotation/Resupply Logistics Profile

Item	Factor	Up Payload (kg)	Down Payload (kg)
Personnel/Personal Effects	48 Men x 110 kg/man	5,280	5,280
On-Orbit Consumables	3.6 kg/Man-Day x (48 Men) x (90 Days)	15,550	*
Consumables Containers	10% of Consumables	1,555	1,555
Passenger Module	200 kg/Man x 48 Men	9,600	9,600
Resupply Module	20% of Consumables	3,110	3,110
OTV Crew Module	Self-Sufficient - 2-Man Crew	2,000	2,000
	TOTAL	37,095 (81,600 lb)	21,545 (47,400 lb)

*Considered as integral part of passenger modules

Electric Orbital Transfer Vehicles (EOTV)

The requirement for low thrust, high specific impulse propulsion systems to transfer satellites or their materials from LEO-to-GEO stems from the prohibitive propellant demands of chemical orbital transfer systems because of the limited (<490s) specific impulse of foreseeable chemical systems.

The major technology options for the electric OTV propulsion subsystem concern the thruster type, size, and design operating point; the power interfaces between the thrusters and the solar array or other primary source; and the propellant type, storage, and distribution.

The accelerator and discharge power sources are small solar arrays near the thrusters. This location reduces cabling mass at the low voltage involved; plasma discharge is negligible. Because only 50 kW per thruster is generated, thermally induced voltage transients can be regulated by voltage limiters. An auxiliary power unit (APU), charged by the discharge supply solar array, furnishes 278 W at 90-percent efficiency to the thruster low-voltage supplies. The power sources and conditioning are illustrated in Figure 105.

The ion thruster propellant selection criteria are availability, storability, absence of serious environmental impacts, cost, demonstrated performance, and technical suitability. Availability becomes a major issue when it is recognized that more than 10^6 kg of propellant is required for one satellite of the SPS type. Technical factors are as follows:

- *High Specific Impulse* - At a given beam voltage, $I_{sp} \propto 1/\sqrt{m_i}$, where m_i is the ion mass.

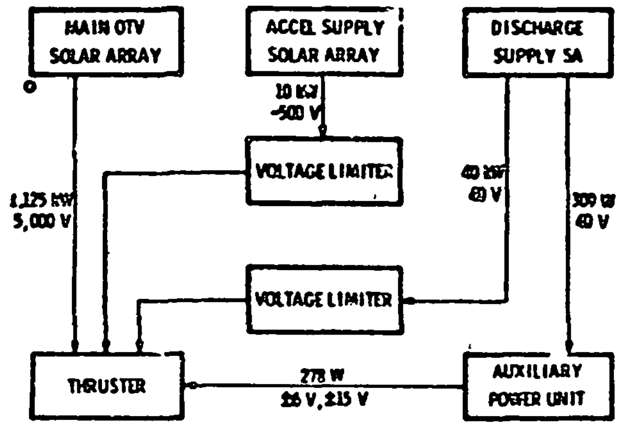

Figure 105. Power Source and Conditioning

- *High Thrust* - At a given beam voltage and current, $T \sim m_i$.
- *Low Vaporization Temperature* - Allows instantaneous thruster restart after solar eclipses without power storage for preheating.
- *Low First-Ionization Potential* - Limits thruster discharge loss and minimizes the efficiency loss due to neutral atoms.
- *High Second-Ionization Potential* - Minimizes the efficiency loss due to multiple ions.

Obviously, the first two factors are mutually contradictory and are best compromised by an ion of medium mass.

The propellants for which ion bombardment thruster experimental data exist are evaluated against the above criteria in Table 10. The selection of argon is self-evident.

Table 10. Ion Propellant Selection Criteria

PROPELLANT	AVAILABILITY	STORABILITY	ENVIRONMENTAL FACTORS	COST ($/KG)	THRUSTER TECHNOLOGY STATUS	ATOMIC WEIGHT	VAPORIZATION TEMP. (K)	IONIZATION POTENTIALS (V) 1	IONIZATION POTENTIALS (V) 2
ARGON	HIGH (0.9% OF AIR)	CRYOGENIC	INERT	0.50	GROUND TESTS	39.9	97	15.76	27 62
CESIUM	PROBABLY INADEQUATE	SOLID	EXTREMELY REACTIVE	300	LABORATORY DEVELOP.	132.9	951	3.89	25 1
XENON	VERY SCARCE	CRYOGENIC	INERT	1000	LABORATORY DEVELOP.	131.3	167	12 13	21.2
MERCURY	MARGINAL	LIQUID	TOXIC	55	SPACE FLT	200.6	530	10 43	19.13

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The electric OTV configuration shown in Figure 106 is sized to accommodate a payload capability of approximately 4×10^6 kg. The structural configuration is essentially the same as employed for future space structures, and is sized to produce approximately 264 megawatts at the thruster modules.

The thruster array is suspended by cables and located at the vehicle c.g. The thruster array is comprised of six subarrays (6 x 30 m), each of which is capable of being packaged in the winged-HLLV cargo bay. Approximately 259 one-meter electric thrusters are required for primary thrust. Additional attitude control thruster packages are located at the structural extremities. Primary thrust vector control is accomplished by a slip ring joint identical to the type used for SPS antenna orientation. A component and payload mass summary is presented in Table 11.

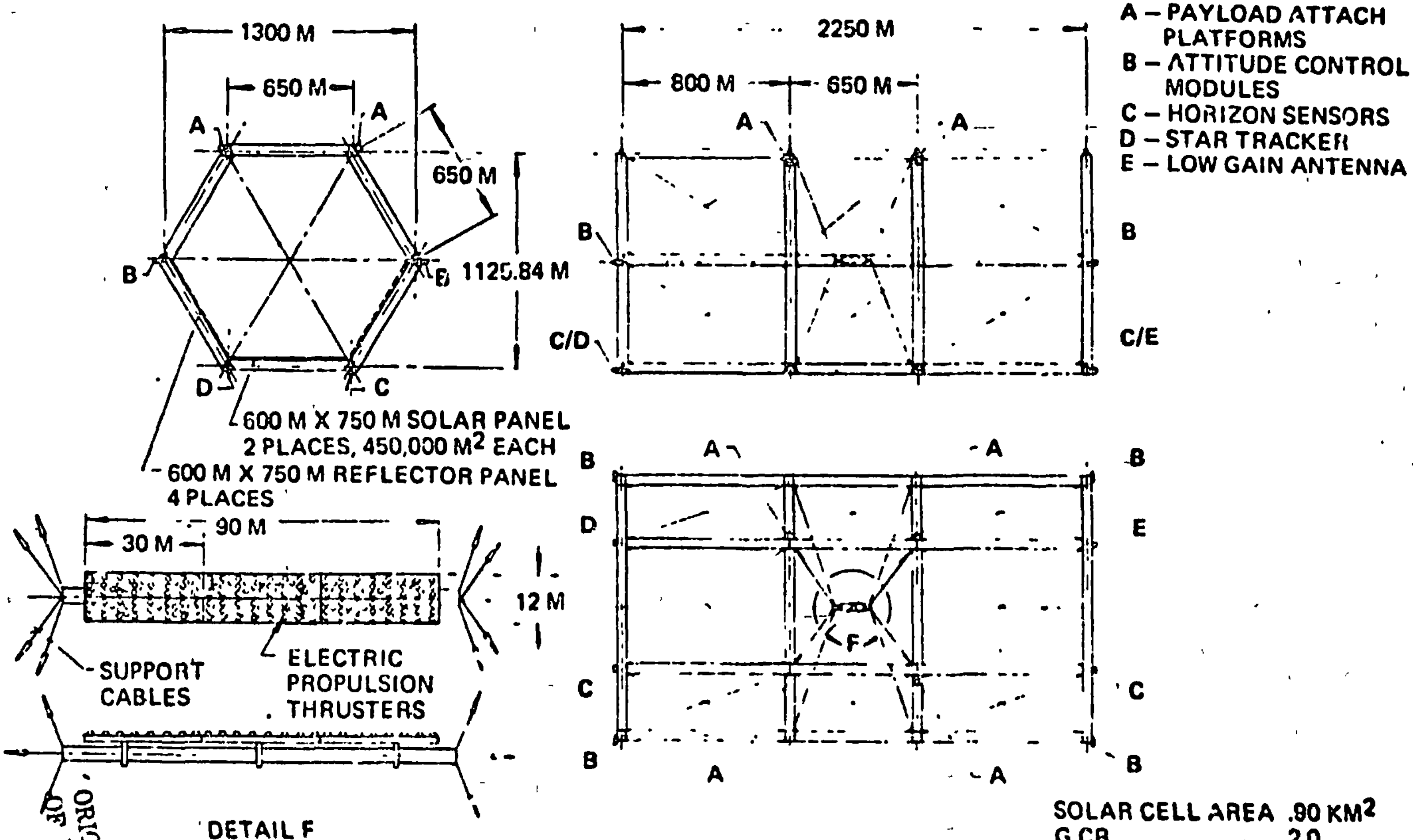
Table 11. OTV Component and Payload Mass Breakdowns (15 Percent Degradation)

Component	Mass (kg)
Solar Array and Reflector	304,057
Power Distribution	372,109
Thruster Modules	31,080
Propellant (Up)	186,864
Propellant (Down)	60,636*
Propellant Tanks and Lines	49,500
Structure	62,046
Rotary Joint	321,85[illegible]
A/C	53,770
OTV Mass (BOL)	1,441,947
Payload Mass	3,935,053
BOL Mass in LEO	5,377,000

*Includes a margin of 8733 kg (14.4 percent)

Transportation System Overview

Typical orbital operations are depicted in Figures 107 and 108. Figure shows the winged HLLV arriving at LEO base where a small on-orbit tug is used to transfer cargo/personnel to the LEO base or chemical OTV's and/or transfer cargo to the electric COTV. The use of the on-orbit tug reduces the maneuver requirements and probability of collision between orbital elements. Figure depicts an electric COTV arriving at GEO to support construction of a solar power satellite. Again an on-orbit tug is employed to maintain a safe separation distance between the rather large space structures.



SOLAR CELL AREA	.90 KM^2
G CR	2.0
MIRROR ANGLE	60°
L/W	1.81

Figure 106. Electric Cargo Orbital Transfer Vehicle

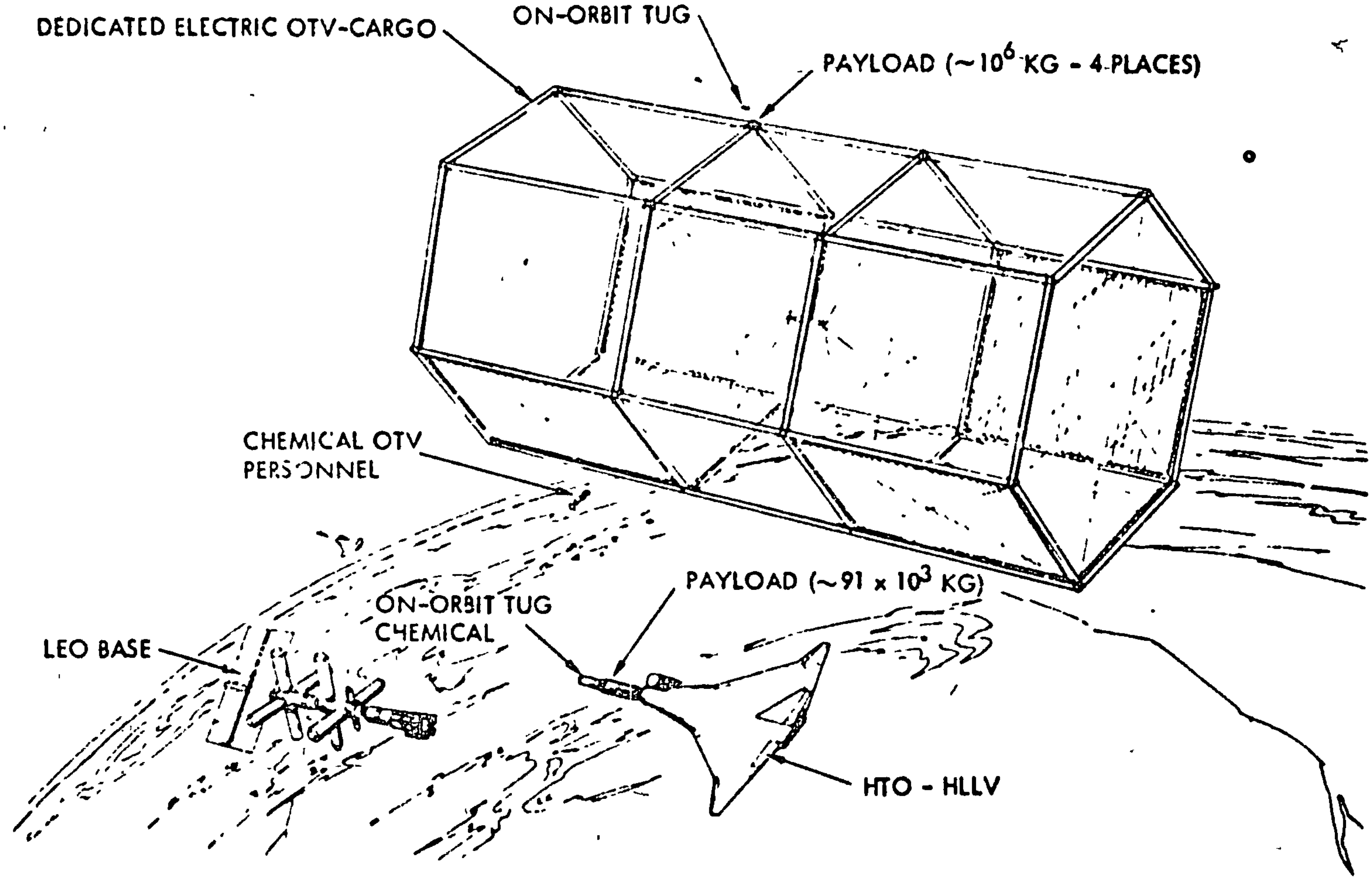


Figure 107. Selected Transportation System Concept

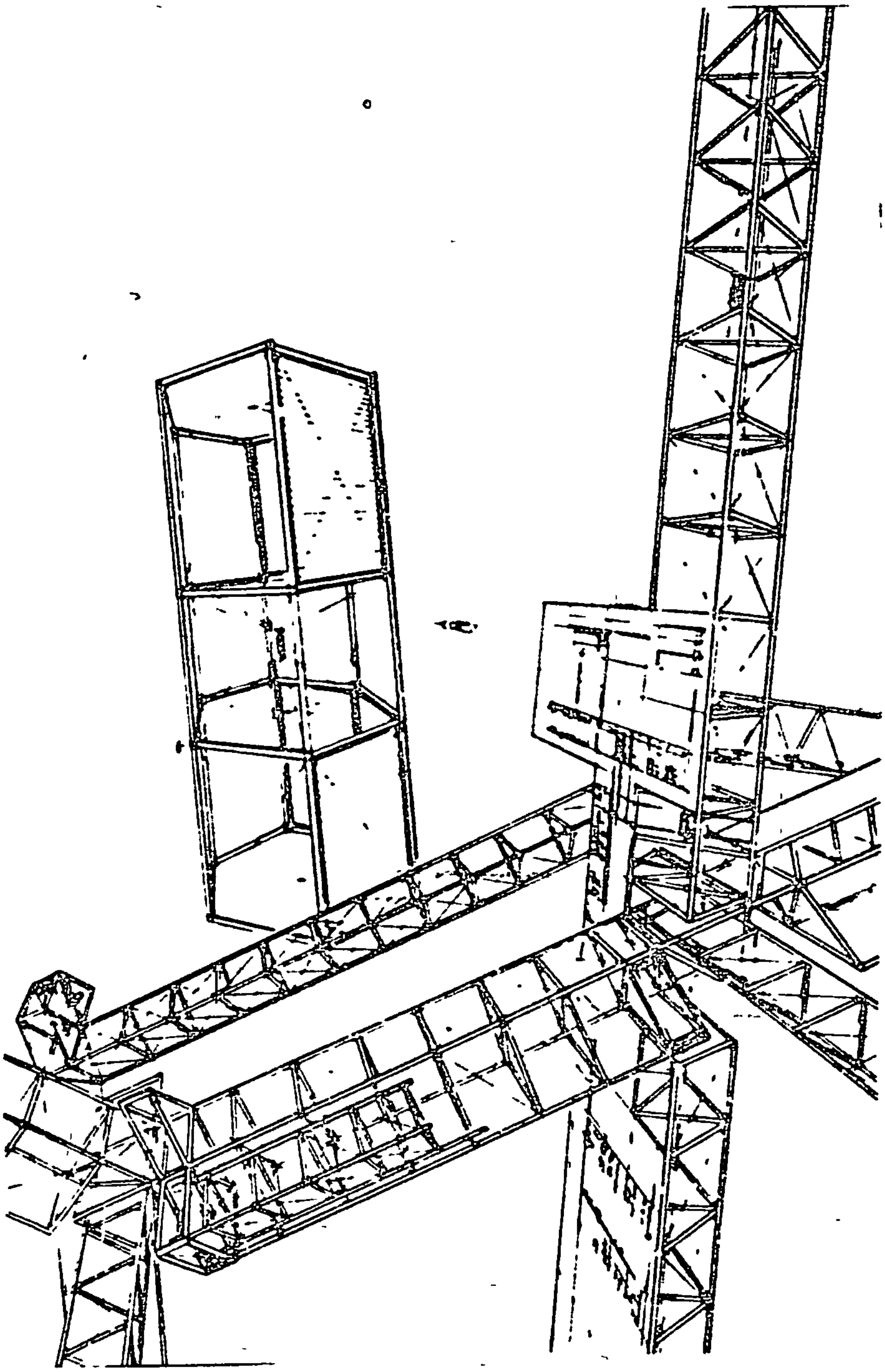


Figure 108. Electric COTV for the SPS at GEO

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RECOMMENDED PLAN PROGRAMMATICS

RECOMMENDED PLAN PROGRAMMATICS

INTRODUCTION

A major output of Part I of this study was a list of *anchor opportunities*. In order to assess the programmatic implications (e.g., cost, time, funding, schedule) inherent in the selected opportunities, it is necessary to integrate the opportunities into evolutionary, time-phased programs, to estimate the developmental and the operational costs, to determine the potential sources of the required funding, and to aggregate the costs into total funding requirements. In this way, the budgetary implications of the space industrialization activities can be determined. In the process, improved cost data will be needed. Furthermore, by comparing the funding requirements with revenues produced for various anchor opportunities, it will be possible to ascertain their cash flows, break-even periods, and overall financial merits.

APPROACH

Background Assumptions

In implementing baseline Plan B, 65 anchor opportunities and support programs were identified, costed, and integrated into the overall schedule. Because some opportunities may be eliminated from contention by future in-depth analyses or competitive terrestrial developments, while others are added to the list, flexibility to accommodate changes was basic to the study efforts. Each anchor opportunity was treated individually, and its impact on aggregated results was purposely made highly visible to facilitate potential modifications.

Since the validity of the aggregated programmatic cost data would be directly dependent on the validity of the costs ascribed to the various anchor opportunities, it was necessary in many instances to generate preliminary designs based on essential technological and economic realities governing practical applications of the respective opportunities. Effort was focused on establishing costs that would be valid within about ±50 percent. Constant dollars (1977) were used throughout the programmatic analysis.

The various anchor opportunities were scheduled (phased within the integrated *space industrialization* program) based on a balance of considerations. Among these were the strength of the need for the anchor opportunity, its technological feasibility, and the reasonableness of logical evolutionary progression of capabilities. The duration of the development period was based on the experience of analogous systems adjusted for relative complexity and extent of inheritance from prior programs (legacy).

Programmatic costs were estimated separately for the system acquisition phase (non-recurring) and for the operations phase (recurring). A basic system life of ten years on orbit was assumed. It was further assumed that charges for the system's use would be sufficient to replace the system after ten years. The acquisition costs included estimates of non-recurring costs of both the space segments and ground segments (e.g., mission control, data reception center, etc.). The operational costs were assumed to be borne by the "owner" of the system. The one-time cost of transporting the space segment to its orbital location was also included in the acquisition costs. If the nature of the operation was such that periodic revisits were required, then these transportation costs were included in the annual operating costs. Basically, the annual operating costs included costs of servicing the space segment (when required) and operating the ground segment. A grey area was encountered in the cost stream of some opportunities that was resolved by arbitrarily truncating costs so as to include only new, out-of-pocket costs associated with implementation of the opportunity. For example, the operating costs associated with crop forecasting were truncated with the data receiving center. The Department of Agriculture's existing staff and computers would perform the analysis of the data, therefore, their annual costs were not assessed against the crop forecasting opportunity.

Each major opportunity was analyzed to determine its logical source of funding. Consequently, four potential sources of funding were identified (1) NASA, (2) other U.S. Government agencies, (3) foreign governmental or international agencies, and (4) commercial. The programmatic costs were aggregated by these four funding categories.

<u>Costing Methodology</u>

A goal of the costing methodology was to produce estimates that would fall within ±50 percent of the actual cost. Several sources of cost data and approaches to cost estimating were employed. For those opportunities that were on-going or planned programs, cost data were extracted from budget hearings. In a number of cases, preliminary designs had to be generated and, in these, parametric costing was employed. In other cases, studies had been performed (or were in process) and their cost data were used (after review for acceptability). Finally, the costs of some opportunities were determined by scaling from analogous designs. A 0.6 scaling factor was found to yield close approximations (i.e., ±10 percent) when tested between two known cost data points, and so was used to cost analogous systems when other data were lacking.

When a parametric costing approach was used, it was generally based on Cost Estimating Relationships (CER's) found in the SAMSO unmanned spacecraft cost model.[1] These cost estimating relationships yielded cost data in terms of 1974 dollars. In several instances, Shuttle-derived cost data were used. When applying analogous costing to a system of different complexity than the reference system, relative complexity factors were used. Similarly, a cost reduction factor of 0.95 per annum was used in some instances to reflect technological advancement (diverse legacies accruing from on-going programs).

To project from direct acquisition costs of spacecraft or mission equipment to system programmatics costs (e.g., including integration, test, management, etc.), a factor of 1.538 times the direct hardware cost was used

[1] <u>SAMSO Unmanned Spacecraft Cost Model</u>, SAMSO TR-75-229 (July 1975).

(excluding transportation costs). This factor was obtained from a study[1] which analyzed the composition of the costs of eight spacecraft programs by cost categories and showed the percent of total program cost attributable to each major cost category. Transportation costs and capabilities for the use of the Shuttle, Interim Upper Stage (IUS) or Solar Electric Propulsion System (SEPS) were based on MSFC-provided data. Costs and capabilities of the Heavy Lift Launch Vehicle (HLLV) were obtained from Shuttle growth studies performed in-house.

Acquisition cost data were spread on a 40:60 ogive over the development years shown in the schedule data. Forty percent of the acquisition costs were shown to be incurred over the first half of the development time, and the remaining 60 percent over the second half. By thus apportioning the acquisition costs and annual operating costs of each anchor opportunity to the corresponding years and then aggregating the costs by year, by each of the four funding agencies (i.e., NASA, other U.S. Government, other governments, and commercial), their annual funding requirements were developed

Payloads carried on the Geosynchronous Platform (GP) and Polar Platform (PP) were assessed a pro-rated annual charge sufficient to enable recovery of platform costs in ten years with an annual return of 10 percent.

The use of single source data carries with it the potential for substantial error. To preclude—or at least, diminish--the possibilities of such errors, all cost estimates were tested for reasonableness by comparison with cost data from other sources.

SCOPE AND LIMITATIONS

The basic analysis was limited to the anchor opportunities that comprised Plan B (SPS program terminated in 1987), and primarily to those that would become operational prior to 1990. To project beyond 1990 would require definition of second-generation (or even third-generation) hardware. The difficulty of extrapolating beyond the first generation of space industrialization would introduce uncertainties arising from assumptions of technological advances and economic needs so as to make any conclusions highly suspect (speculative). Consequently, major effort was focused on space industrialization programmatics in the 1980-1990 time period, and on the initial activities essential to space exploitation.

The programmatic analysis was limited to the 65 anchor opportunities identified at the end of Part I of this study. Admittedly, some of those eliminated may be implemented within the next decade, while some of the 65 may not. Developments in laser beam propagation and holography could result in holographic TV, teleconferencing, or other applications which were not included in the basic 65. The 65 anchor opportunities should be viewed as illustrative of the potentials of space industrialization.

[1]Kitchen, Lawrence D., Manpower Cost Estimation Model: Automated Planetary Projects. Science Applications, Inc., SAI 1-120-194-C1 (March 1975).

TECHNICAL DATA

The following sections present programmatic and descriptive data on the 65 recommended opportunities.

Schedule of Recommended Opportunities

Each of the 65 anchor opportunities was analyzed to determine its location in the orderly, evolutionary implementation of space industrialization Table 12 shows the resulting implementation schedule by calendar year of the selected opportunities in the baseline plan. The opportunities are enumerated chronologically in their order of implementation within the various categories. The D's denote acquisition periods, while O's indicate operational status. R's indicate a research and development phase, and an X denotes an opportunity-concluding demonstration test.

System development/acquisition was assumed to begin the the fourth quarter of the first year designated, and be completed at the conclusion of the third quarter of the last year designated. Cost data spreads reflected this scheduling assumption.

Summarized Cost Data by Recommended Opportunities

The summarized cost data corresponding to each of the 65 recommended opportunities are shown in their scheduled sequence in Table 13 The anticipated source of funding (NASA, other U.S Government agencies, other governments or consortia, or commercial) is identified for each opportunity.

Descriptions of Recommended Opportunities

Brief descriptions, along with cost and funding spread data, are presented in the following section for each of the 65 recommended opportunities. The sequence of presentation is that used earlier in establishing the schedule sequences by categories.

1. TIME AND NAVIGATION SERVICES

Potential market area - The Time and Navigation Satellite (NAVSTAR-GPS) is designed to provide suitably equipped vehicles with three-axis positional data to within about 10 meters at any point in the world. While Loran D provides two-axis positional data to within about [illegible]0 meters, it is limited to coastal regions covered by Loran stations. In addition to position data, the system will also provide accurate time reference data. The system is scheduled to be completed and operational in 1985.

Responsible agency - Department of Defense (DOD)

Assumptions/ground rules/limitations - The system is currently under development.

Table 12. Schedule of Selected Anchor Opportunities—Plan B

ANCHOR OPPORTUNITY WITHIN CATEGORY	IMPLEMENTATION SCHEDULE - CALENDAR YEAR															
	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95
SERVICES - INFORMATION TRANSMISSION																
1. TIME AND NAVIGATION SERVICES	D	D	D	D	D	D	O	—	—	—	—	—	—	—	→	O
2. ELECTRONIC MAIL - USA	D	D	D	D	D	D	O	—	—	—	—	—	—	—	→	O
3. POCKET TELEPHONES - USA		D	D	D	D	D	O	—	—	—	—	—	—	—	→	O
4. DIR BROADCAST EDUCATION - USA		D	D	D	D	D	O	—	—	—	—	—	—	—	→	O
5. BUSINESS SYST DATA XFER - USA		D	D	D	D	D	O	—	—	—	—	—	—	—	→	O
6. ELECTR TELECONFERENCING - USA		D	D	D	D	D	O	—	—	—	—	—	—	—	→	O
7. IMPLANTED SENSOR DATA COLLECTOR - USA		D	D	D	D	D	O	—	—	—	—	—	—	—	→	O
8. ELECTRONIC MAIL - EUR/AFR			D	D	D	D	D	O	O	—	—	—	—	—	→	O
9. POCKET TELEPHONE - EUR/AFR				D	D	D	D	D	O	—	—	—	—	—	→	O
10. DIR BROADCAST ED - EUR/AFR				D	D	D	D	D	O	—	—	—	—	—	→	O
11. WORLD MEDICAL ADVICE CEN. (USA)				D	D	D	D	D	O	—	—	—	—	—	→	O
12. BUS SYST DATA XFER - EUR/AFR					D	D	D	D	O	—	—	—	—	—	→	O
13. ELECTR TELECONF - EUR/AFR					D	D	D	D	O	—	—	—	—	—	→	O
14. MEDICAL AID & INFORMATION, USA					D	D	D	D	D	O	—	—	—	—	→	O
15. ELECTRONIC MAIL - ASIA					D	D	D	D	D	D	O	—	—	—	→	O
16. POCKET TELEPHONES - ASIA						D	D	D	D	D	O	—	—	—	→	O
17. ELECTRONIC TELECOMMUTING						R	R	D	D	D	D	D	D	O	→	O
18. DIR BROADCAST EDUCATION, ASIA							D	D	D	D	O	—	—	—	→	O
19. BUS SYST DATA TRANSFER, ASIA							D	D	D	D	O	—	—	—	→	O
20. ELECTR TELECONFERENCING - ASIA							D	D	D	D	O	—	—	—	→	O
21. NATIONAL INFORMATION SERVICES											D	D	D	D	D	D
SERVICES - OBSERVATION																
22. LANDSAT D	D	D	O	—	—	—	—	—	—	—	→	O				
23. SEASAT B	D	D	D	D	O	—	—	—	—	—	—	—	→	O		
24. OIL/MINERAL LOCATION		D	D	D	D	D	O	—	—	—	—	—	—	—	→	O
25. WATER RES MAP & DYN. SYS A			D	D	D	D	D	O	—	—	—	—	—	—	→	O
26. TOPOGRAPHIC MAPPING			D	D	D	D	D	D	O	—	—	—	—	—	→	O
27. WATER RES MAP & DYN SYS B				D	D	D	D	D	O	—	—	—	—	—	→	O
28. CROP MEASUREMENT A B C				D	D	D	D	D	O	—	—	—	—	—	→	O
29. GLOBAL EFFECTS MONITORING A B				D	D	D	D	D	O	—	—	—	—	—	→	O
30. WATER RES MAP & DYN SYS C					D	D	D	D	O	—	—	—	—	—	→	O
31. OCEAN RES & DYN SYS A B C					D	D	D	D	O	—	—	—	—	—	→	
32. MICROWAVE RADIOMETER					R	D	D	D	D	D	O	—	—	—	→	
33. LUNAR ORBITER						D	D	D	D	D	O	—	—	—	→	O
34. HIGH-RES RESOURCE SURVEY							D	D	D	D	D	O	—	—	→	O
35. HIGH-RES RADAR MAPPING							R	D	D	D	D	D	O	—	→	O
36. LUNAR UNMANNED EXPLORERS										R	D	D	D	D		O

Table 12. Schedule of Selected Opportunities—Plan B (Cont.)

ANCHOR OPPORTUNITY WITHIN CATEGORY	IMPLEMENTATION SCHEDULE - CALENDAR YEAR															
	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95
PRODUCTS (REPRESENTATIVE)																
ORGANIC																
37 ISOENZYMES (SPACE BASE FAC.)			R	D	D	D	D	O								O
38. UROKINASE (SPACE BASE FACILITY)				D	D	D	D	D	O							O
39. INSULIN (SPACE BASE FACILITY)				D	D	D	D	D	O							O
INORGANIC																
40 LARGE CRYSTALS		D	O	D	D	D	O									O
41. SUPER LARGE-SCALE INTEGRATED CIRCUITS		D	O	D	D	D	O									O
42 NEW GLASSES			D	O	D	D	D	O								O
43 HI-TEMP TURBINE BLADES			D	D	D	D	D	O								O
44 HI-STRENGTH PERM MAGNETS				D	D	D	D	D	O							O
45 CUTTING TOOLS				D	D	D	D	D	O							O
46 THIN-FILM ELECTR DEVICES					D	D	D	D	D	O						O
47 CONTINUOUS RIBBON CRYST GROWTH					D	D	D	D	D	O						O
ENERGY																
48 SOLAR PWR SYST DEVELOPMENT (1)	R	R	R	R	R	R	R	-								
49 NIGHT ILLUM (LUNETTA)									R	D	D	D	D	O		O
PEOPLE IN SPACE																
50 MEDICAL AND GENETIC RESEARCH (SPACE BASE)			D	D	D	D	D	O								O
SUPPORT ELEMENTS																
FUNCTIONAL																
51 SHUTTLE/SPACELAB	D	O														O
52 EXTENDED-DURATION ORBITER/ 25-KW POWER MODULE	D	D	D	D	O											O
53 ADVANCED TELEOPERATOR		D	D	D	D	O										O
54. GEOSYNCHRONOUS PLATFORM USA		D	D	D	D	D	O									O
55. LOW EARTH ORBIT BASE		R	D	D	D	D	D	O								O
56. POLAR PLATFORM A				D	D	D	D	O								O
57. GEOSYNCH PLATFORM - EUR/AFR				D	D	D	D	D	O							O
58. LUNETTA DEMONSTRATION					D	D	D	D	X							
59. POLAR PLATFORM B					D	D	D	D	O							O
60 POLAR PLATFORM C						D	D	D	D	O						O
61. GLOBAL WEATHER & RESOURCE BASE						D	D	D	D	D	O					O
62 GEOSYNCHRONOUS PLATFORM - ASIA						D	D	D	D	D	O					O
TRANSPORTATION																
63. LOW-THRUST OTV (SEPS)	D	D	D	D	D	O										O
64. HLLV-1 (SHUTTLE W/O ORBITER)						D	O	D	D	D	O					O
65 OTV (LARGE CHEMICAL)		R	D	D	D	D	D	O								O

Table 13. Summarized Cost Data—By Anchor Opportunity (1977 $M)

ANCHOR OPPORTUNITY WITHIN CATEGORY	SOURCE OF FUNDS	NON RECURRING COST				ANN OPER COST		
		TOTAL	SPACE	GROUND	TRANSP	TOTAL	SPACE	GROUND
SERVICES – INFORMATION TRANSMISSION								
1 TIME AND NAVIGATION SERVICES	OTH US	381.0	–	–	–	10.0	–	10.0
2. ELECTRONIC MAIL – USA	OTH US	2487.9	246.0	2219.1	21.8	404.5	8.0	478.8
3 POCKET TELEPHONES – USA	COMM	540.3	315.5	5.0	21.8	16.0	0.0	10.0
4 DIR BROADCAST EDUCATION – USA	COMM	205.5	186.4	8.1	11.0	38.0	28.0	10.0
5 BUSINESS SYST DATA XFER – USA	COMM	171.0	155.0	5.0	11.0	18.0	8.0	10.0
6 ELECTR TELECONFERENCING – USA	COMM	91.6	73.3	11.0	7.0	18.0	8.0	10.0
7 IMPLANTED SENSOR DATA COLLECTOR – USA	OTH US	340.3	313.5	5.0	21.8	18.0	8.0	10.0
8 ELECTRONIC MAIL – EUR/AFR	OTH GOV	207.8	186.0	–	21.8	8.0	8.0	–
9 POCKET TELEPHONES – EUR/AFR	OTH. GOV	261.9	235.1	5.0	21.8	16.0	6.0	10.0
10 DIR BROADCAST ED – EUR/AFR	OTH GOV	168.9	139.8	8.1	11.0	38.0	28.0	10.0
11 WORLD MEDICAL ADVICE CEN (USA)	OTH US	171.0	155.0	5.0	11.0	16.0	6.0	10.0
12. BUS SYST DATA XFER – EUR/AFR	OTH GOV	132.2	116.2	5.0	11.0	18.0	8.0	10.0
13 ELECTR TELECONF – EUR/AFR	OTH GOV	91.6	73.6	11.0	7.0	18.0	8.0	10.0
14 MEDICAL AID & INFORMATION, USA	OTH US	396.0	155.0	230.0	11.0	128.0	8.0	120.0
15 ELECTRONIC MAIL – ASIA	OTH GOV	207.8	186.0	–	21.8	8.0	8.0	–
16 POCKET TELEPHONES – ASIA	OTH GOV	261.9	235.1	5.0	21.8	18.0	6.0	10.0
17 ELECTRONIC TELECOMMUTING	COMM	166.0	155.0	–	11.0	18.0	8.0	10.0
18. DIR BROADCAST EDUCATION, ASIA	OTH GOV	158.9	139.8	8.1	11.0	38.0	28.0	10.0
19 BUS SYST DATA TRANSFER, ASIA	OTH GOV	132.2	116.2	5.0	11.0	18.0	8.0	10.0
20 ELECTR TELECONFERENCING – ASIA	OTH GOV	91.6	73.5	11.0	7.0	18.0	8.0	10.0
21 NATIONAL INFORMATION SERVICES	OTH US	426.3	313.5	91.0	21.8	8.0	8.0	–
SERVICES – OBSERVATION								
22 LANDSAT D	NASA	128.8	–	–	–	10.0	–	
23. SEASAT B	NASA	96.0	73.0	10.0	13.0	10.0	–	10.0
24 OIL/MINERAL LOCATION	NASA	201.0	180.0	10.0	11.0	10.0	–	10.0
25 WATER RES MAP & DYN SYS. A	OTH US	76.0	60.0	5.0	11.0	12.0	2.0	10.0
26 TOPOGRAPHIC MAPPING	NASA	201.0	180.0	10.0	11.0	10.0	–	10.0
27 WATER RES. MAP & DYN SYS B	OTH US	71.0	60.0	–	11.0	2.0	2.0	–
28 CROP MEASUREMENT A B C	OTH US	206.0	180.0	5.0	21.8	18.0	8.0	10.0
29 GLOBAL EFFECTS MONITORING A B	OTH US	146.8	120.0	5.0	21.8	14.0	4.0	10.0
30. WATER RES MAP & DYN SYS C	OTH US	71.0	60.0	–	11.0	2.0	2.0	–
31 OCEAN RES. & DYN SYS. A B C	OTH US	206.8	180.0	5.0	21.8	18.0	8.0	10.0
32. MICROWAVE RADIOMETER	NASA	900.7	717.7	10.0	173.0	10.0	–	10.0
33 LUNAR ORBITER	NASA	208.6	180.0	10.0	18.6	10.0	–	10.0
34 HIGH RES. RESOURCE SURVEY	NASA	201.0	180.0	10.0	11.0	10.0	–	10.0
35. HIGH RES. RADAR MAPPING	NASA	301.8	270.0	10.0	21.8	10.0	–	10.0
36 LUNAR UNMANNED EXPLORERS	NASA	352.8	300.0	10.0	42.8	10.0	–	10.0

Table 13. Summarized Cost Data—By Anchor Opportunity (1977 $M) Cont.

ANCHOR OPPORTUNITY WITHIN CATEGORY	SOURCE OF FUNDS	NON RECURRING COST				ANN OPER COST		
		TOTAL	SPACE	GROUND	TRANSP	TOTAL	SPACE	GROUND
PRODUCTS (REPRESENTATIVE)								
ORGANIC								
37 ISOENZYMES (SPACE BASE FACILITY)	COMM	116.0	100.0	5.0	11.0	7.0	7.0	-
38 UROKINASE (SPACE BASE FACILITY)	COMM	226.8	200.0	5.0	21.8	7.0	7.0	-
39 INSULIN (SPACE BASE FACILITY)	COMM	226.8	200.0	5.0	21.8	7.0	7.0	-
INORGANIC								
40 A LARGE CRYSTALS 40A	NASA	218.2	213.2	5.0	-	-	-	-
40 B LARGE CRYSTALS 40B	COMM	267.3	126.5	5.0	130.8	21.8	21.8	2.0
41 SUPER LARGE SCALE INTEGRATED CIRCUITS	COMM	267.3	126.5	10.0	130.8	21.8	21.8	2.0
42 NEW GLASSES	COMM	267.3	126.5	10.0	130.8	21.8	21.8	2.0
43 HI TEMP TURBINE BLADES	COMM	267.3	126.5	10.0	130.8	21.8	21.8	2.0
44 HI STRENGTH PERM MAGNETS	COMM	267.3	126.5	10.0	130.8	21.8	21.8	2.0
45 CUTTING TOOLS	COMM	267.3	126.5	10.0	130.8	21.8	21.8	2.0
46 THIN FILM ELECTRONIC DEVICES	COMM	267.3	126.5	10.0	130.8	21.8	21.8	2.0
47 CONTINUOUS RIBBON CRYST GROWTH	COMM	267.3	126.5	10.0	130.8	21.8	21.8	2.0
ENERGY								
48 A SOLAR PWR SYST DEVELOPMENT	NASA	46.8	20.0	5.0	21.8	-	-	-
48 B SOLAR PWR SYST DEVELOPMENT	OTH US	3000.0	-	-	-	-	-	-
49 NIGHT ILLUM (LUNETTA)	OTH US	2757.0	2247.0	10.0	500.0	20.0	10.0	10.0
PEOPLE IN SPACE								
50 MEDICAL AND GENETIC RESEARCH (SPACE BASE)	NASA	116.0	100.0	5.0	11.0	15.0	10.0	5.0
SUPPORT ELEMENTS								
FUNCTIONAL								
51 SHUTTLE/SPACELAB	NASA	2621.6	-	-	-	-	-	-
52 EXTENDED DURATION ORBITER/ 25 KW POWER MODULE	NASA	161.8	130.0	10.0	21.8	10.0	-	10.0
53 ADVANCED TELEOPERATOR	NASA	167.0	150.0	10.0	7.0	10.0	-	10.0
54 GEOSYNCHRONOUS PLATFORM USA	NASA	281.4	155.7	10.0	115.7	10.0	-	10.0
55 LOW EARTH ORBIT BASE	NASA	323.8	292.0	10.0	21.8	92.2	87.2	5.0
56 POLAR PLATFORM A	NASA	103.5	71.7	10.0	21.8	5.0	-	5.0
57 GEOSYNCH PLATFORM EUR/AFR	OTH GOV	281.4	155.7	-	115.7	10.0	-	10.0
58 LUNETTA DEMONSTRATION	NASA	81.8	50.0	10.0	21.8	-	-	-
59 POLAR PLATFORM B	NASA	64.8	43.0	-	21.8	5.0	-	5.0
60 POLAR PLATFORM C	NASA	64.8	43.0	-	21.8	5.0	-	5.0
61 GLOBAL WEATHER & RESOURCE BASE	OTH GOV	553.6	500.0	10.0	43.6	97.2	87.2	10.0
62 GEOSYNCHRONOUS PLATFORM – ASIA	OTH GOV	281.4	155.7	-	115.7	10.0	-	10.0
TRANSPORTATION								
63 LOW THRUST OTV (SEPS)	NASA	225.0	193.2	10.0	21.8	10.0	-	10.0
64 HLLV 1 (SHUTTLE W/O ORBITER)	NASA	1981.8	1950.0	10.0	21.8	10.0	-	10.0
65 OTV (LARGE CHEMICAL)	NASA	631.8	600.0	10.0	21.8	10.0	-	10.0

- *Space operations* - A network of 24 satellites is required for full operational capability. Early satellites will be launched by conventional boosters. The first Shuttle-launched satellites will be emplaced in 1983.

- *Ground operations* - A mission control center is assumed at a nominal cost of $10 million per year.

Cost data - The basic source was modified program data. The aggregated data obtained for non-recurring costs were not divided into space, ground, or transportation categories.

- *Non-recurring cost* - $381 million

- *Annual operating cost* - $10 million

System acquisition funding requirements - (1977 $M)

TOTAL	1980	1981	1982	1983	1984	1985
381.0	25.0	69.0	56.0	91.0	70.0	70.0

2. ELECTRONIC MAIL—USA

Potential market area - This system as defined would be a U.S. postal system service. Letters written on a standardized form would be physically transferred from one of the 30,000 local post offices to the nearest regional center (RC). At the center, a facsimile of the letter would be transmitted via relay satellite and reproduced at the regional center nearest its destination. The facsimile copy would be physically transported to the local post office serving its destination for next-day delivery; 845 regional centers would need to be equipped for automated electronic mail processing.

Responsible agency - U.S. Postal Service

Assumptions/ground rules/limitations - The system would be capable of handling 40 million pieces/day. "Electronic Mail" was defined as facsimile reproduced material processed and delivered by the postal service. Excluded were word processors or private facsimile transmission. A description of the concept was presented in an earlier section of this report.

- *Space operations* - Antennas and electronic packages were assumed to be emplaced on a geosynchronous platform.

- *Ground operations* - All 845 regional centers were assumed to be equipped with highly automated equipment for processing the electronic mail.

Cost data - Cost estimates were derived primarily from cost estimating relationships as applied to preliminary design specifications.

- *Non-recurring cost (1977 $M)*

Space segment	248.0	
Ground segment	2218.1	(for 875 RC's)
Transportation to LEO	21.8	
Total	2487.9	

- *Annual operating cost ($M)*

Space segment (GP)	6.0
Ground segment	478.5
Total	484.5

System acquisition funding requirements ($1977 $M)

TOTAL	1980	1981	1982	1983	1984	1985
2487.9	17.93	399.35	837.87	779.04	378.35	75.37

3. POCKET TELEPHONES—USA

Potential market area - A personal, portable pocket telephone that operates via relay through a geosynchronous orbit satellite constitutes the essence of this concept. Calls would be relayed from the satellite to conventional telephone network stations for transmission through the regular telephone system or, again, via satellite relay to portable phone destinations. Because of battery and antenna size requirements, the personal units were comparable to pocket calculators in size. This concept removes the current range and topography limitations encountered by existing mobile telephones.

Responsible agency - Commercial

Assumptions/ground rules/limitations - The basic design would enable processing of approximately 45,000 simultaneous calls. A description of the concept was presented in an earlier section of this report.

- *Space operations* - The antennas and electronic packages were assumed to be emplaced on the geosynchronous platform.

- *Ground operations* - Conventional telephone systems would be employed for call propagation and billing. Consequently, no new ground facilities were assumed to be required beyond those currently in being or planned (i.e., satellite relay of conventional telephone calls.

Cost data - Cost estimates were derived primarily from CER's applied to preliminary design specifications.

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- *Non-recurring cost ($M)*

Space segment	313.5
Ground segment	5.0
Transportation to LEO	31.8
Total	340.3

- *Annual operating cost ($M)*

Space segment (GP)	6.0
Ground segment (mission control, etc.)	10.0
Total	16.0

The initial cost of the ground unit is $650, reducing down 85-percent learning curve to less than $100.

System acquisition funding requirement (1977 $M)

TOTAL	1981	1982	1983	1984	1985
340.3	3.82	83.35	151.96	84.75	16.42

4. DIRECT BROADCAST EDUCATION

Potential market area - All homes in the U.S. equipped with TV sets could receive five channels of direct broadcast educational TV upon installation of a one-meter-diameter antenna and TV adapter.

Responsible agency - Commercial (e.g., public broadcasting service)

Assumptions/ground rules/limitations - Five channels of specialized broadcasts would be transmitted via the satellite directly to homes. Four transmitting stations—one in each time zone—would be used. A description of the concept may be found in an earlier section.

- *Space operations* - Antennas and electronic packages were assumed to be emplaced on the geosynchronous platform.

- *Ground operations* - A roof-mounted and accurately pointed parabolic antenna would be required. The received signal would need to be processed through an electronic adapter for compatibility with conventional TV sets.

Cost data - Cost estimates were derived primarily from CER's applied to preliminary design specifications.

- *Non-recurring cost ($M)*

Space segment	186.4
Ground segment	8.1
Transportation to LEO (1/2 Shuttle)	11.0
Total	205.5

- *Annual operating cost ($M)*

Space segment	26.0
Ground segment	10.0
Total	36.0

Costs of development of educational TV programs are not included. The initial cost of the TV antenna and adapter is estimated to be $200.

System acquisition funding requirements (1977 $M)

TOTAL	1981	1982	1983	1984	1985
205.5	2.30	50.34	91.77	51.17	9.92

5. BUSINESS SYSTEMS DATA TRANSFER—USA

Potential market area - The anticipated proliferation of word-processor and facsimile units in companies will likely require dedicated satellites. Data would be transmitted via company antennas to a satellite that would relay the data to the appropriate receiving station. This concept would be competitive with telephone lines currently used for such applications, but which are becoming increasingly saturated.

Responsible agency - Commercial

Assumptions/ground rules/limitations - Users of this system would have equipment for transmitting and receiving high-density data via the relay satellite.

- *Space operations* - Antennas and electronic packages were assumed to be emplaced on the geosynchronous platform.

- *Ground operations* - Data would be formatted and compiled within company computers for transmission via relay satellite to other computers where the data would be reconstituted for human use. A computerized system is envisioned for monitoring system use and for customer billing.

Cost data - Cost estimates were generated by analogy to key elements of No. 3, Personal Communications.

- *Non-recurring cost ($M)*

Space segment	155.0
Ground segment	5.0
Transportation to LEO (1/2 Shuttle)	11.0
Total	171.0

- *Annual operating cost ($M)*

Space segment	6.0
Ground segment	10.0
Total	16.0

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Initial cost of the ground units (i.e., antenna plus electronics for computer interface) is assumed to be $30,000.

System acquisition funding requirements (1977 $M)

TOTAL	1981	1982	1983	1984	1985
171.0	1.92	41.88	46.37	42.58	8.25

6. ELECTRONIC TELECONFERENCING—USA

Potential market area - Travel to conferences or business meetings can be substantially reduced through teleconferencing with a resultant reduction in fuel consumption and saving of time. In this concept, real-time views of the groups participating in the conference are televised via relay satellite and displayed to their counterparts on giant-screen TV's.

Responsible agency - Commercial

Assumptions/ground rules/limitations - Approximately 80 to 100 teleconferences could be broadcast simultaneously by the defined system. This number could be expanded by use of stop-frame techniques. Details of the system may be found in previous sections of this report.

- *Space operations* - The space segment was assumed to be mounted on the geosynchronous platform.

- *Ground operations* - Each facility utilizing this concept would require a one-meter antenna for communication with the relay satellite in geosynchronous orbit. Costs of TV cameras, electronic packages, giant-screen TV, etc., per installation were estimated to be $60,000: these costs were not included. Costs for decorating conference rooms and equipping them with conventional furniture were also excluded.

Cost data - Cost estimates were derived primarily from CER's applied to preliminary design specifications.

- *Non-recurring cost ($M)*

Space segment	73.6
Ground segment	11.0
Transportation to LEO (1/2 Shuttle)	7.0
Total	91.6

- *Annual operating cost ($M)*

Space segment	6.0
Ground segment	10.0
Total	16.0

Initial cost of electronics for a teleconferencing facility was estimated to be $60,000.

System acquisition funding requirements (1977 $M)

TOTAL	1981	1982	1983	1984	1985
91.6	1.03	22.43	40.91	22.81	4.42

7. IMPLANTED SENSOR DATA COLLECTOR—USA

Potential market area - In this anchor opportunity, data gathered by diverse, remote sensors are transmitted to a relay satellite which re-transmits them to the appropriate ground receiving station. This system may be viewed as closely related to the personal communications concept inasmuch as data from thousands of sensors (phone calls) will need to be relayed to data reception centers.

Responsible agency - U.S. Government (e.g., Department of Interior) agency.

Assumptions/ground rules/limitations - Data from 45,000 sensors can be received and relayed simultaneously by the space segement. The area of coverage is limited to the contiguous 48 states.

- *Space operations* - Antennas and electronic packages were assumed to be emplaced on the geosynchronous platform.
- *Ground operations* - Costs of the data receiving ground stations were not included because, in many instances, they would be substituted for existing data collection networks. Cost of space payload mission control was included.

Cost data - Cost data were estimated by analogy to No. 3, Personal Communications.

- *Non-recurring cost ($M)*

Space segment	313.5
Ground segment	5.0
Transportation to LEO	21.8
Total	340.3

- *Annual operating cost ($M)*

Space segment	6.0
Ground segment	10.0
Total	16.0

The initial cost of sensor data transmission units would vary widely, depending on the application, life, frequency of transmission, etc.

System acquisition funding requirements (1977 $M)

TOTAL	1981	1982	1983	1984	1985
340.3	3.82	83.35	151.96	84.75	16.42

8. ELECTRONIC MAIL—EUROPE/AFRICA

Potential market area - If electronic mail is implemented in the U.S., then it will likely be expanded to foreign countries. Air mail from the U.S. to Rio de Janeiro takes at least seven days—frequently, 11 days. In this anchor opportunity, electronic mail is implemented among countries in the longitude of Europe/Africa and between these countries and the U.S.

Responsible agency - Foreign government agency/consortium

Assumptions/ground rules/limitations - (See No. 2, Electronic Mail—USA) The non-recurring and annual operating cost of ground installations was not estimated because of uncertainty in the number of stations required. A normalized estimate for the non-recurring cost of each mail station would be on the order of $3.0 million. The annual operating cost per mail station would be on the order of $0.5 million.

Cost data - Cost estimates were derived by analogy to No. 2, Electronic Mail—U.S.

- *Non-recurring cost ($M)*

Space segment	186.0	
Ground segment	-	($3.0M each)
Transportation to LEO	21.8	
Total	207.8	

- *Annual operating cost ($M)*

Space segment	6.0	
Ground segment	-	($0.5M each)
Total	6.0	

System acquisition funding requirements (1977 $M)—space segment only

TOTAL	1982	1983	1984	1985	1986	1987
207.8	*1.50*	*33.36*	*69.99*	*65.06*	*31.60*	*6.29*

9. POCKET TELEPHONES—EUROPE/AFRICA

Potential market area - This anchor opportunity is the application of No. 3, Pocket Telephones — USA to the European/African area.

Responsible agency - Foreign government consortium

Assumptions/ground rules/limitations - See No. 3, Pocket Telephones —USA.

Cost data - Cost estimates were derived by analog to No. 3, Pocket Telephones — USA.

- *Non-recurring cost ($M)*

Space segment	235.1
Ground segment	5.0
Transportation	21.8
Total	261.9

- *Annual operating cost ($M)*

Space segment	6.0
Ground segment	10.0
Total	16.0

System acquisition funding requirements (1977 $M)

TOTAL	1983	1984	1985	1986	1987
261.9	2.94	64.14	116.96	65.22	12.64

10. DIRECT BROADCAST EDUCATION—EUROPE/AFRICA

Potential market area - In this anchor opportunity, the U.S. developed system is installed in the European/African area to provide a similar service there.

Responsible agency - Foreign government consortium

Assumptions/ground rules/limitations - See No. 4, Direct Broadcast Education—USA. The five-TV-channel capacity would be allocated among the nations procuring the system.

Cost data - Cost estimates were derived by analogy to No. 4, Direct Broadcast Education—USA.

- *Non-recurring cost ($M)*

Space segment	139.8
Ground segment	8.1
Transportation to LEO (1/2 Shuttle)	11.0
Total	158.9

- *Annual operating cost ($M)*

Space segment	26.0
Ground segment	10.0
Total	36.0

Cost of developing the educational TV programs is not included. The initial cost of TV antenna and adapter is estimated to be $200.

System acquisition funding requirements (1977 $M)

TOTAL	1983	1984	1985	1986	1987
158.9	1.78	38.93	70.96	39.56	7.67

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11. WORLD MEDICAL ADVICE CENTER--USA

Potential market area - In this anchor opportunity, diverse medical data such as statistical incidence of diseases, clinical analyses, diagnostics, treatment, pharmacology, etc , are all rapidly available from a medical center data bank via satellite relay. While the medical center was assumed to be located in the United States, its data would be accessible worldwide.

Responsible agency - U.S. Government (e.g., Department of HEW) agency.

Assumptions/ground rules/limitations - The key goal of this anchor opportunity is rapid and accurate diagnosis of patients afflicted by obscure diseases or by several diseases simultaneously which may result in unconventional symptoms, thus taxing the ability of even highly capable physicians. It focuses on lesser known diseases along with the most recent findings of their symptoms. laboratory tests, and treatment.

- *Space operations* - The antennas and electronic packages were assumed to be emplaced on the geosynchronous platform.

- *Ground operations* - Real-time color TV (stop-frame mode) pictures of patients and their afflictions can be relayed between the users and the medical advice center.

Cost data - Cost estimates of the space segment were derived by analogy to No. 5, Business Systems Data Transfer. Cost of the ground segment was limited to mission control operations because of lack of potential market data.

- *Non-recurring cost ($M)*

Space segment	155.0
Ground segment	5.0
Transportation to LEO (1/2 Shuttle)	11.0
Total	171.0

- *Annual operation cost ($M)*

Space segment	6.0
Ground segment	10.0
Total	16.0

The initial cost of a ground terminal was estimated to be on the order of $30,000.

System acquisition funding requirement (1977 $M)

TOTAL	1983	1984	1985	1986	1987
171.0	1.92	41.88	76.37	42.58	8.25

12. BUSINESS SYSTEMS DATA TRANSFER—EUROPE/AFRICA

Potential market area - Multi-national corporations will desire to exchange data among their facilities and subsidiary companies. This anchor opportunity is an application of No. 5, Business Systems Data Transfer to the European/African region, including the Middle East.

Responsible agency - Because communication systems are nationalized in most foreign countries, the responsible agency for this anchor opportunity will likely be a foreign government consortium.

Assumptions/ground rules/limitations - See No. 5, Business Systems Data Transfer—USA.

Cost data - Cost estimates were generated by analogy to No. 5, Business Systems Data Transfer—USA.

- *Non-recurring cost ($M)*

Space segment	116.2
Ground segment	5.0
Transportation to LEO (1/2 Shuttle)	11.0
Total	132.2

- *Annual operating cost ($M)*

Space segment	6.0
Ground segment	10.0
Total	16.0

System acquisition funding requirements (1977 $M)

TOTAL	1984	1985	1986	1987
132.2	2.62	55.30	62.58	11.70

13. ELECTRONIC TELECONFERENCING--EUROPE/AFRICA

Potential market area - The same benefits that would accrue from domestic (U.S.) teleconferencing would also result from teleconferencing among European/African companies and between U.S. and European/African facilities.

Responsible agency - Foreign government consortium

Assumptions/ground rules/limitations - See No. 6, Electronic Teleconferencing—USA.

Cost data - Cost estimates were derived by analogy to No. 6, Electronic Teleconferencing—USA.

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- *Non-recurring cost ($M)*

Space segment	73.6
Ground segment	11.0
Transportation to LEO (1/3 Shuttle)	7.0
Total	91.6

- *Annual operating cost ($M)*

Space segment	6.0
Ground segment	10.0
Total	16.0

Initial cost for a teleconferencing facility was estimated to be $60,000.

System acquisition funding requirements (1977 $M)

TOTAL	1984	1985	1986	1987
91.6	1.81	38.31	43.36	8.12

14 MEDICAL AID AND INFORMATION—USA

Potential market area - Two kinds of medical data are provided in this anchor opportunity. Patient medical histories are provided to paramedics so that appropriate treatment can be quickly initiated. The system also links paramedics with doctors and specialists who can participate in the diagnosis and guide the emergency treatment by proxy. The second aspect of this anchor opportunity links doctors, medical clinics, and hospitals with a diagnostic computer.

Responsible agency - U.S. Government (e.g., Department of HEW) agency.

Assumptions/ground rules/limitations - A description of this concept is presented in an earlier section of this report. The basic system may be compared to No. 5, Business Systems Data Transfer—USA.

- *Space operations* - The antennas and electronic packages were assumed to be emplaced on the geosynchronous platform.

- *Ground operations* - Communication terminals are located in doctors' offices, medical clinics, and hospitals in addition to being mounted on emergency medical vehicles. A single diagnostic computer is located at a national facility, where its programs are continuously updated to incorporate the most recent medical findings.

Cost data - Cost estimates of the space segment were derived by analogy to No. 5, Business Systems Data Transfer—USA. Costs of the ground segment were generated primarily by parametric costing.

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- *Non-recurring cost ($M)*

Space segment	155.0
Ground segment	230.0
Transportation	11.0
Total	396.0

- *Annual operating cost ($M)*

Space segment	6.0
Ground segment	120.0
Total	126.0

The average initial cost of a ground terminal was estimated to be $5690, based on a buy of 10,000.

System acquisition funding requirements (1977 $M)

TOTAL	1984	1985	1986	1987	1988
396.0	4.44	96.99	176.87	98.60	19.10

15 ELECTRONIC MAIL—ASIA

Potential market area - This anchor opportunity extends electronic mail to the Asian theater, and between Asia/U.S. and Asia/Europe/Africa.

Responsible agency: Foreign government (Japan) or consortium

Assumptions/ground rules/limitations - See No. 8, Electronic Mail—Europe/Africa.

Cost data - Cost data were estimated by analogy to No. 2, Electronic Mail—USA. As in No. 8, Electronic Mail—Europe/Africa, the cost of ground stations was not estimated. See No. 8 for cost data.

System acquisition funding requirements (1977 $M)

TOTAL	1984	1985	1986	1987	1988	1989
207.8	1.50	33.36	69.99	65.06	31.60	6.29

16. POCKET TELEPHONES—ASIA

Potential market area - This anchor opportunity is an extension of No. 3, Pocket Telephone—USA; and No. 9, Pocket Telephones—Europe/Africa to the Asian area. It also connects Asian countries and countries served by the two former opportunities.

Responsible agency - Foreign government (Japan) or consortium

Assumptions/ground rules/limitations - See No. 3, Pocket Telephones—USA.

Cost data - Cost estimates were derived by analogy to No. 3, Pocket Telephones—USA. See No. 9, Pocket Telephones—Europe/Africa for cost data.

System acquisition funding requirements (1977 $M)

TOTAL	1985	1986	1987	1988	1989
261.9	2.94	64.14	116.96	65.22	12.64

17. ELECTRONIC TELECOMMUTING

Potential market area - In a number of service industries, form (paper) processing is the major activity. In this anchor opportunity, the paper processing operation would be decentralized into neighborhood centers that are electronically linked to a central computer. Thereby, paper-processing employees would not need to travel to central (downtown) office facilities with resultant savings in time and gasoline. The service companies would also benefit by having the work done in lower-cost facilities. Widespread implementation of telecommuting would necessitate a dedicate space payload to link the form-processing centers with the central computer(s).

Responsible agency - Commercial

Assumptions/ground rules/limitations - A description of this concept may be found in an earlier section. Service companies employing telecommuting would lease capacity on a continuing, permanent basis.

- *Space operations* - The antenna and electronic packages were assumed to be emplaced on the geosynchronous platform.

- *Ground operations* - Both the paper processing centers and the computer centers would have antennas and interfacing electronics. Each paper-processing center would have many CRT terminals —all connected to a remote computer via satellite relay.

Cost data - Cost estimates of the space segment were derived by analogy to No. 5, Business Systems Data Transfer—USA. The ground segment cost data apply only to the mission control/system management center.

- *Non-recurring cost ($M)*

Space segment	150.0
Ground segment	5.0
Transportation to LEO (1/2 Shuttle)	11.0
Total	166.0

- *Annual operating costs ($M)*

Space segment	6.0
Ground segment	10.0
	16.0

Initial cost of CRT consoles was estimated at $1000 each. The cost of interfacing electronics at the processing center was estimated to be $50,000 and at the computer center, $30,000.

System acquisition funding requirements (1977 $M)

TOTAL	1985	1986	1987	1988	1989	1990
166.0	1.20	26.65	55.90	51.98	25.24	5.03

18. DIRECT BROADCAST EDUCATION—ASIA

Potential market area - This anchor opportunity is an extension of No. 4, Direct Broadcast Education—USA, to the Asian area.

Responsible agency - Foreign government (Japan/China/India) or consortium

Assumptions/ground rules/limitations - See No. 4, Direct Broadcast Education—USA. The five TV channels would be allocated among the nations procuring the system.

Cost data - See No. 10, Direct Broadcast Education—Europe/Africa, for cost data.

System acquisition funding requirements (1977 $M)

TOTAL	1986	1987	1988	1989
158.9	3.14	66.45	75.23	14.08

19. BUSINESS SYSTEMS DATA TRANSFER—ASIA

Potential market area - The same drivers which justified the U.S. and European/African versions of this anchor opportunity would mandate its installation into the Asian area.

Responsible agency - Foreign government consortium

Assumptions/ground rules/limitations - See No. 5, Business Systems Data Transfer—USA.

Cost data - See No. 12, Business Systems Data Transfer—Europe/Africa for cost data.

System acquisition funding requirements (1977 $M)

TOTAL	1986	1987	1988	1989
132.2	2.62	55.30	62.58	11.70

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20. ELECTRONIC TELECONFERENCING—ASIA

Potential market area - Much of the time and cost required for travel to the Orient for business meetings could be saved by a teleconferencing link to the Asian area. Furthermore, intra-Asian teleconferencing would likely be justified by 1990. This anchor opportunity would complete a world-wide teleconferencing network through Numbers 6 and 13, Electronic Teleconferencing—USA and —Europe/Africa, respectively.

Responsible agency - Foreign government consortium

Assumptions/ground rules/limitations - See No. 6, Electronic Teleconferencing—USA.

Cost data - See No. 13, Electronic Teleconferencing—Europe/Africa for cost data.

System acquisition funding requirements (1977 $M)

TOTAL	1986	1987	1988	1989
91.6	1.81	38.31	43.36	8.12

21. NATIONAL INFORMATION SERVICES

Potential market area - The cost of storing data electronically is rapidly approaching the cost of storage on a printed page. Extrapolation of this trend, coupled with the problem of providing space in libraries for the books and journals printed every year, indicates a possible solution in electronic storage of books and journals. This storage mode would enable computer search and retrieval of data from a major repository, such as the Library of Congress. Experience with the more than 200 computer-based commercial data files that can be remotely searched will facilitate design and development of a national data retrieval system.

Responsible agency - U.S. Government (e.g., Department of HEW) agency.

Assumptions/ground rules/limitations - A home CRT terminal or the equivalent would be required for interactive dialogue with the data searching computer. Charges would be based on the duration of the hookup.

- *Space operations* - Antennas and electronics for relay were assumed to be emplaced on the geosynchronous platform.

- *Ground operations* - Either commercial telephone lines, cable to a transmitting facility, or home antennas for satellite relay, could be used to link the home units with the computer.

Cost data - Cost estimates were derived primarily through CER's applied to system specifications and by analogy to No. 3, Personal Communications—USA.

- *Non-recurring cost ($M)*

Space segment	313.5
Ground segment	91.0*
Transportation to LEO	21.8
Total	426.3

- *Annual operating cost ($M)*

Space segment	6.0
Ground segment	**

The initial cost of the interactive home terminals was estimated to be on the order of $600.

System acquisition funding requirements (1977 $M)

TOTAL	1987	1988	1989	1990	1991	1992
426.3	3.07	68.42	143.59	133.49	64.82	12.91

22. LANDSAT D

Potential market area - Landsat D, scheduled to be launched in 1981, was included as an anchor opportunity because of the highly beneficial (commercially) data anticipated from its advanced sensors.

Responsible agency - NASA

Assumptions/ground rules/limitations - Although designed for a seven-year life, a ten-year operational life was assumed because of the extended lifetimes of its predecessors. Furthermore, it was assumed that Landsat D would not be replaced because the several special-function satellites would be routinely providing earth surface data in approximately 28 spectral frequencies, which is several times the capability of Landsat D.

- *Space operations* - Landsat D is a single, dedicated spacecraft, and will provide an 18-day repeat overflight cycle.

- *Ground operations* - Facilities, currently being expanded, for receiving and processing Landsat data were assumed to be adequate for Landsat D.

*Includes cost of computer and conversion of high-use items to electronic storage and development of author royalty reimbursement system.

**Annual operating costs of Library of Congress facility were not included because a detailed analysis would be required to determine whether the proposed system would result in increased costs.

Cost data - The basic source of the cost data was budget hearings. Because the hearings data were not divided into space segment and ground segment, only the lumped sum was used.

- *Non-recurring cost ($M)* - 128.8
- *Annual operating cost ($M)* - 10.0

System acquisition funding requirements (1977 $M)

TOTAL	1980	1981
128.8	97.5	31.3

23. SEASAT B

Potential market area - If the substantial benefits anticipated from Seasat A materialize, then a more frequent overflight cycle will be desired. Seasat B was included because its addition would result in doubling the frequency of sea condition observations.

Responsible agency - NASA

Assumptions/general rules/limitations - Acquisition of Seasat B was assumed to begin in 1980. The satellite was assumed to have a 10-year life.

- *Space operations* - Seasat B was assumed to be a single, dedicated spacecraft. Seasat B would use Seasat A's mission control.
- *Ground operations* - Attainment of maximum commercial benefits from the Seasat A and B system was assumed to require expanded ground facilities for more rapid data analysis and dissemination.

Cost data - The source of Seasat B cost data was Seasat A budget hearings.

- *Non-recurring cost ($M)*

Space segment	73.0
Ground segment	10.0
Transportation (non-Shuttle)	13.0
Total	96.0

- *Annual operating cost ($M)*

Space segment	—
Ground segment	10.0
Total	10.0

System acquisition funding requirements (1977 $M)

TOTAL	1980	1981	1982	1983
96.0	1.90	40.16	45.44	8.50

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24. OIL/MINERAL LOCATION

Potential market area - This anchor opportunity consists of a dedicated satellite similar to Landsat D, but with sensors especially selected for the detection of oil and/or mineral deposits (i.e., tar sands, lignite, peat, etc.). Oil deposits might be sought by detecting oil-revealing slicks floating on surface water after rains in sparsely inhabited regions

Responsible agency - NASA; this would be a developmental satellite to test feasibility of concept.

Assumptions/general rules/limitations - The spacecraft is assumed to have a ten-year life. Although total earth coverage should be attainable (with minor exceptions) within several years, the occurrence of unique conditions essential to mineral detection would take longer (e.g., oil slicks on snow melt runoff).

- *Space operations* - The spacecraft was assumed to be a single, dedicated satellite.

- *Ground operations* - Additional data processing and mission control facilities were assumed to be required.

Cost data - The cost estimates were derived by analogy to Landsat D.

- *Non-recurring cost ($M)*

Space segment	180.0
Ground segment	10.0
Transportation (Polar—1/2 Shuttle)	11.0
Total	201.0

- *Annual operating cost ($M)*

Space segment	—
Ground segment	10.0
Total	10.0

System acquisition funding requirements (1977 $M)

TOTAL	1981	1982	1983	1984	1985
201.0	2.25	49.22	89.76	50.06	9.69

25 WATER RESOURCE MAPPING AND DYNAMIC SYSTEMS—A

Potential market area - Water management is becoming increasingly recognized as a critical government function. Demands on water resources need to be balanced for optimal benefit. This anchor opportunity would provide basic data for water management on national, regional, state, and local levels.

Responsible agency - U.S. Government (e.g., Department of Agriculture or Department of Interior) agency.

Assumptions/ground rules/limitations - Approximately seven sensors, sensitive to spectral frequencies related to water detection and flow monitoring, were assumed to be carried on the space payload. The payload was assumed to be mounted on a common polar platform (Platform A—No. 56—would give 18-day repeat coverage) along with several similar payloads that are obtaining data on identical target areas, but in other spectral frequencies. A description of the polar platform can be found in another section of this report. The "A" in the title signifies the first of three identical payloads (A, B, and C), spaced to give six-day repeat coverage.

- *Space operations* - The payload antennas, sensors, and electronic package would be emplaced (prior to launch or by the Shuttle) on a polar (sun-synchronous) platform. Data would be relayed via TDRS to a ground receiving station or to an orbital data processing facility (see No. 55, Low Earth Orbit Base).

- *Ground operations* - Dedicated ground facilities were assumed for data analysis and rapid dissemination.

Cost data - Cost estimates were generated by analogy to the Landsat D costs.

- *Non-recurring cost ($M)*

Space segment	60.0
Ground segment	5.0
Transportation to polar orbit (1/2 Shuttle)	11.0
Total	76.0

- *Annual operating cost ($M)*

Space segment (Platform A)	2.0
Ground segment	10.0
Total	12.0

System acquisition funding requirements (1977 $M)

TOTAL	1982	1983	1984	1985	1986
76.0	0.85	18.61	33.94	18.93	3.67

26. TOPOGRAPHIC MAPPING

Potential market area - Planning for efficient transportation, irrigation, and resource development requires accurate topographic data. Conventional means for acquiring these data are many times more expensive than their acquisition via satellite. The *Stereosat*, described in the February 21, 1978 issue of Defense/Space Daily (p. 273), is similar in many respects to the concept envisioned in this anchor opportunity

Responsible agency - NASA (because satellite is basically *developmental* rather than *operational*).

Assumptions/ground rules/limitations - The spacecraft was assumed to be a single-purpose, dedicated satellite. Data from the satellite would be relayed via TDRS to a ground station or to a data processing station in low earth orbit (see No. 55, Low Earth Orbit Base). Techniques are being refined for direct development of topographic maps through computer processing of the data.

- *Space operations* - A ten-year life was assumed for the satellite. Stereoscopic data would be obtained for predetermined areas by programming of the satellite operations.

- *Ground operations* - Automated computer-controlled, topographic map-making machines would be used to produce maps from the satellite data.

Cost data - Cost estimates were derived by analogy to Landsat cost data.

- *Non-recurring cost ($M)*

Space segment	180.0
Ground segment	10.0
Transportation to polar orbit (1/2 Shuttle)	11.0
Total	201.0

- *Annual operating cost ($M)*

Space segment	—
Ground segment	10.0
Total	10.0

System acquisition funding requirements (1977 $M)

TOTAL	1982	1983	1984	1985	1986	1987
201.0	1.45	32.26	67.70	62.93	30.57	6.09

27. WATER RESOURCE MAPPING AND DYNAMIC SYSTEMS—B

Potential market area - This anchor opportunity is an adjunct to No. 25, Water Resource Mapping and Dynamic Systems—A. This is the second of three payloads spaced so as to give six-day repeat coverage. It follows Platform A by two years.

Responsible agency - See No. 25.

Assumptions/ground rules/limitations - See No. 25. Ground segments established for No. 25 are used here without any additional cost. Polar Platform B is No. 59.

Cost data - Cost estimates are generated by analogy to Landsat D costs.

- *Non-recurring cost ($M)*

Space segment	60.0
Ground segment	—
Transportation to polar orbit (1/2 Shuttle)	11.0
Total	71.0

- *Annual operating cost ($M)*

Space segment (Platform B)	2.0
Ground segment	—
Total	2.0

System acquisition funding requirements (1977 $M)

TOTAL	1983	1984	1985	1986	1987
71.0	0.80	17.40	31.69	17.68	3.43

28. CROP MEASUREMENT—A, B, C

Potential market area - Attempts at forecasting key crop harvests based on Landsat A and B data have been very encouraging. Large Area Crop Inventory Experiment (LACIE) and other programs are verifying the feasibility of crop measurement by satellite. This anchor opportunity produces worldwide forecasts of crop yields—thus facilitating generation of prudent agricultural policies.

Responsible agency - U.S. Government (e.g., Department of Agriculture) agency.

Assumptions/ground rules/limitations - Approximately seven crop detecting/resolving sensors are integrated in each of three identical payloads. The three payloads are mounted on Polar Platforms A, B, and C (Numbers 56, 59, and 60, respectively). A description of the polar platform can be found in another section of this report.

- *Space operations* - The three payloads are equally spaced in a common sun-synchronous orbit so that repeat coverage is obtained every six days.

- *Ground operations* - The acquired data would be analyzed by computer and crop forecasts developed and updated for key crops on a worldwide basis; the data would be disseminated internationally.

Cost data - Cost estimates were obtained by analogy to the Landsat D cost data.

- *Non-recurring cost ($M)*

Space segment	180.0
Ground segment	5.0
Transportation to polar orbit (1 Shuttle)	21.8
Total	206.8

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- *Annual operating cost ($M)*

Space segment (for three payloads)		6.0
Ground segment		10.0
	Total	16.0

System acquisition funding requirements (1977 $M)

TOTAL	1983	1984	1985	1986	1987
206.8	2.32	50.65	92.36	51.49	9.98

29 GLOBAL EFFECTS MONITORING—A, B

Potential market area - The U.S. Weather Bureau is gradually increasing the accuracy and range of its forecasts. Acquisition and interpretation of key data are essential to the continuation of this trend. In this anchor opportunity, magnetospheric data plus other data are acquired by payloads attached to Polar Platforms A and B in sun-synchronous orbit. These data are integrated with data from other sensors (e.g., in geosynchronous orbit and on space stations) to enable improved longer range weather forecasts.

Responsible agency - U.S. Government (e.g., Department of Commerce) agency.

Assumptions/ground rules/limitations - These payloads are in a grey area between scientific research and commercial applications and are included as an anchor opportunity because of the highly beneficial impacts that would result from even a marginally improved weather forecasting capability.

- *Space operations* - Data acquired by the two payloads (120 degrees apart) are relayed via TDRS to ground stations or to a space base in low earth orbit (see No. 55) for processing prior to earth relay

- *Ground operations* - Data would be fed into a weather modeling computer. Because weather modeling computers already exist, neither hardware nor software costs were included.

Cost data - Cost estimates were derived by analogy to Landsat D cost data.

- *Non-recurring cost ($M)*

Space segment (two payloads)		120.0
Ground segment		5.0
Transportation to polar orbit		21.8
	Total	146.8

- *Annual operating cost ($M)*

Space segment (two platforms)		4.0
Ground segment		10.0
	Total	14.0

System acquisition funding requirements (1977 $M)

TOTAL	1983	1984	1985	1986	1987
146.8	1.65	35.95	65.56	36.55	7.09

30. WATER RESOURCE MAPPING AND DYNAMIC SYSTEM—C

Potential market area - This anchor opportunity is part of Numbers 25 and 27, Water Resource Mapping and Dynamic Systems—A and —B, respectively. It is the third of three payloads spaced 120 degrees apart in a common sun-synchronous orbit so as to provide six-day repeat coverage. Its acquisition follows the B-payload acquisition by one year.

Responsible agency - See No. 25.

Assumptions/ground rules/limitations - See Numbers 25 and 27.

Cost data - See No. 27.

System acquisition funding requirements (1977 $M)

TOTAL	1984	1985	1986	1987
71.0	1.40	29.69	33.62	6.29

31. OCEAN RESOURCES AND DYNAMIC SYSTEMS—A, B, C

Potential market area - Based on data acquired from Seasats A and B, Landsat D, and other satellites, information will be available for the development of payloads designed to detect major schools of fish and krill-rich areas. Compilation and analysis of oceanic data will enable more efficient fishing and, possibly, management of fish resources.

Responsible agency - U.S. Government (e.g., Department of Commerce) agency.

Assumptions/ground rules/limitations - Each of the three identical payloads was assumed to contain approximately seven sensors that operate at spectral frequencies selected so as to provide discriminatory data to enable detection of schools of fish and krill.

- *Space operations* - The three payloads are mounted on platforms spaced 120 degrees apart in a polar (sun-synchronous) orbit, so as to provide repeat coverage every six days. Data are relayed via TDRS to ground stations, or to a data processing facility in low earth orbit (see No. 55), for relay to earth.

- *Ground operations* - The key function to the ground operations is to disseminate data to fishing fleets that have contracted for the service.

Cost data - Cost estimates were generated by analogy to Landsat D data.

- *Non-recurring cost ($M)*

Space segment (three payloads)	180.0
Ground segment	5.0
Transportation	21.8
Total	206.8

- *Annual operating cost ($M)*

Space segment (three platforms)	6.0
Ground segment	10.0
Total	16.0

System acquisition funding requirements (1977 $M)

TOTAL	1984	1985	1986	1987	1988
206.8	2.32	50.65	92.36	51.49	9.98

32. MICROWAVE RADIOMETER

Potential market area - A large microwave radiometer will provide data which, when analyzed and combined with data from other sources, will yield unique clues to potentially valuable resources.

Responsible agency - NASA

Assumptions/ground rules/limitations - The spacecraft was assumed to be a single, dedicated satellite. Because of the ground resolution desired, it would be very large. Design data and specifications of the satellite are described in another section of the report.

- *Space operations* - The satellite would be in a relatively low-altitude, high-inclination (polar) orbit. Data would be relayed via TDRS to a ground station, or to a data processing station in low earth orbit (see No. 55). The satellite would provide repeated ground coverage every 18 to 20 days.

- *Ground operations* - Time-sensitive data, such as iceberg location, would be quickly forwarded to the U.S. Coast Guard. Data not time-sensitive would be analyzed and results provided to requesting agencies and/or customers.

Cost data - Cost estimates were derived primarily from CER's applied to preliminary design specifications.

- *Non-recurring cost ($M)*

Space segment	717.7
Ground segment	10.0
Transportation	173.0
Total	900.7

- *Annual operating cost ($M)*

Space segment		—
Ground segment		10.0
	Total	10.0

System acquisition funding requirements (1977 $M)

TOTAL	1984	1985	1986	1987	1988	1989
900.7	6.49	144.57	303.35	282.04	136.96	27.29

33. LUNAR ORBITER

Potential market area - The lunar orbiter is a forerunner of missions leading to the possible establishment of a manned lunar colony after the turn of the century.

Responsible agency - NASA

Assumptions/ground rules/limitations - The lunar orbiter was assumed to be similar to Landsat D. It would be placed in a polar lunar orbit from which it would map lunar resources. Sufficient data storage capacity would be provided so that data acquired while on the back side of the moon could be compressed, stored, and sent to earth simultaneously with the transmission of data being acquired on the front-side pass. The payload would carry about seven sensors, each responsive to a different spectral frequency.

- *Space operations* - The lunar orbiter was assumed to draw upon hardware developed for the 1960's lunar orbiter, the Viking orbiter, and the Landsats. Its RCS system would enable it to lower its orbit altitude and go into an alternative (high-speed, narrower width) scan mode in order to provide substantially higher resolution of sites of interest.

- *Ground operations* - Data would be relayed via TDRS to a ground station for processing and analysis.

Cost data - Cost estimates were generated by analogy to Landsat D cost data.

- *Non-recurring cost ($M)*

Space segment		180.0
Ground segment		0.0
Transportation (HLLV + 2 IUS's)		18.6
	Total	208.6

- *Annual operating cost ($M)*

Space segment		—
Ground segment		10.0
	Total	10.0

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System acquisition funding requirements (1977 $M)

TOTAL	1985	1986	1987	1988	1989
208.6	2.34	51.09	93.17	51.94	10.06

34 HIGH-RESOLUTION RESOURCE SURVEY

Potential market area - Resource surveys by Landsat D are limited by a resolution capability on the order of 100 feet. Certain mineral outcroppings or other resource indicators may be overlooked at that resolution. This anchor opportunity incorporates a satellite with a resolving capability on the order of 25 feet to search for exploitable resources.

Responsible agency - NASA

Assumptions/ground rules/limitations - The satellite was assumed to be a single, dedicated spacecraft placed into sun-synchronous orbit, and equipped with approximately seven sensors.

- *Space operations* - A 7- to 10-year satellite lifetime was assumed. Repeat ground coverage was assumed to occur every 18 days. The data rate would be about 16 times that of Landsat D. Conceivably, laser communications would be used. Data would be relayed via TDRS (or a laser version by 1990) to a data processing station in low earth orbit (see No. 55).

- *Ground operations* - Mission Control was assumed to program the satellites' operational cycles. Data would be processed by facilities added to those of the Landsats. Dedicated computers would be required for the analyses.

Cost data - Cost estimates were derived by analogy to Landsat D cost data.

- *Non-recurring cost ($M)*

Space segment		180.0
Ground segment		10.0
Transportation to polar orbit (1/2 Shuttle)		11.0
	Total	201.0

- *Annual operating cost ($M)*

Space segment		—
Ground segment		10.0
	Total	10.0

System acquisition funding requirements (1977 $M)

TOTAL	1986	1987	1988	1989	1990
201.0	2.25	49.22	89.78	50.06	9.69

35. HIGH-RESOLUTION RADAR MAPPING

Potential market area - Those regions that are usually cloud-covered, or which were impossible to map by satellite or airborne systems, would be mapped by radar in this anchor opportunity. An imaging radar (synthetic aperture) with some on-board processing was assumed which would provide ground resolution on the order of 50 feet.

Responsible agency - NASA (because of the developmental nature of the sateilite).

Assumptions/ground rules/limitations - The radar-mapping satellite was assumed to be a single, dedicated spacecraft in polar orbit.

- *Space operations* - During pre-programmed operational periods, data would be transmitted in real time via TDRS to a ground station or to a data processing station in low earth orbit (see No. 55).
- *Ground operations* - Because of a large degree of standardization in the received data, ground computers would readily analyze the data and generate maps.

Cost data - Cost data were generated by extrapolation from other satellite costs.

- *Non-recurring cost ($M)*

Space segment	270.0
Ground segment	10.0
Transportation to polar orbit	21.8
Total	301.8

- *Annual operating cost ($M)*

Space segment	—
Ground segment	10.0
Total	10.0

System acquisition funding requirements (1977 $M)

TOTAL	1986	1987	1988	1989	1990	1991
301.8	2.18	48.45	101.63	94.50	45.90	9.14

36 LUNAR UNMANNED EXPLORERS

Potential market area - Following the lunar orbiter (No. 33), lunar unmanned explorers (rovers) would be sent to the lunar surface to confirm lunar orbiter data and to explore likely sites for manned scientific and mineral-processing colonies that might be established in the late 1990's or early 2000's.

Responsible agency - NASA

Assumptions/ground rules/limitations - The lunar explorers were assumed to be a combination of the lunar roving vehicle (LRV) from the Apollo program and the Viking with some teleoperation-type capability.

- *Lunar operations* - A traverse distance on the order of 50 miles (per battery set) was assumed. Two additional battery sets were assumed to be stored at the landing site.

- *Ground operations* - Communications with the unmanned explorers would be maintained through ground stations linked by earth satellite relay to a central mission control.

Cost data - Cost estimates were obtained by analogy to former space programs and assumed a substantial legacy from them.

- *Non-recurring cost ($M)*

Lunar segment	300.0
Ground segment	10.0
Transportation (HLLV + OTV)	42.8
Total	352.8

- *Annual operating cost ($M)*

Lunar segment	—
Ground segment	10.0
Total	10.0

System acquisition funding requirements (1977 $M)

TOTAL	1989	1990	1991	1992	1993	1994
352.8	2.54	56.63	118.83	110.47	53.65	10.69

37. ISOENZYMES (SPACE BASE FACILITY)

Potential market area - This anchor opportunity is *representative* of pharmaceuticals to be produced in an orbiting space base facility.

Responsible agency - Commercial

Assumptions/ground rules/limitations - This anchor opportunity was assumed to be representative of pharmaceuticals that, while life-saving, would need to be produced in relatively small quantities. Consequently, it was assumed that the product(s) would be produced at the medical and genetic research facility (see No. 50) by its general-purpose equipment. Consequently, the cost of acquiring the facility was assumed to be divided equally between this anchor opportunity and No. 50, Medical and Genetic Research.

- *Space operations* - Costs of space operations include transportation of materials for processing plus costs that are reflective of the man-hours required and equipment use charges. Less than 12,000 lb of pharmaceuticals were assumed to be produced per year.

- *Ground operations* - Upon return to earth, the processed pharmaceuticals were assumed to enter conventional product streams; therefore, no additional out-of-pocket costs assessable to space processing were assumed.

Cost data - Cost estimates were derived from recent space base and laboratory studies.

- *Non-recurring costs, $M (1/2 of actual total—see No. 50)*

Space segment	100.0
Ground segment	5.0
Transportation	11.0
Total	116.0

- *Annual operating cost ($M)*

Space segment	7.0
Ground segment	—
Total	7.0

System acquisition funding requirements (1977 $M)

TOTAL	1982	1983	1984	1985	1986
116.0	1.30	28.42	51.80	28.88	5.60

38. UROKINASE
39. INSULIN

Potential market area - These two opportunities were assumed to be *representative* of those pharmaceuticals that would be required in large quantities and therefore would be produced in dedicated facilities (modules) attached to a space base.

Responsible agency - Commercial

Assumptions/ground rules/limitations - Approximately 50,000 lb of each of the two products were assumed to be produced per year. Logistics missions that would require one fourth of the Shuttle capacity for each product were assumed to occur every three months.

- *Space operations* - Periodic maintenance by space station personnel was assumed to be required, and man-hour charges for these services are included in the cost data as are the charges for energy consumed.

- *Ground operations* - No charges for ground operations were assessed because, upon return to earth, the processed pharmaceuticals were assumed to enter conventional product streams.

Cost data - Cost estimates were derived from space station studies which included data on space processing modules. The following data are applicable to both No. 38 (Urokinase) and No. 39 (Insulin).

- *Non-recurring cost ($M)*

Space segment	200.0
Ground segment	5.0
Transportation	21.8
Total	226.8

- *Annual operating cost ($M)*

Space segment	7.0
Ground segment	—
Total	7.0

System acquisition funding requirements (1977 $M)

TOTAL	1983	1984	1985	1986	1987
226.8	2.54	55.55	101.29	56.48	10.94

40A LARGE CRYSTALS (NASA PROCESSING FACILITY DEVELOPMENT)*

Potential market area - This anchor opportunity is divided into the NASA-funded development of a generic space processing facility (No. 40A) and the actual production and equipment of processing facilities with unique processing hardware (Numbers 40B through 47). The economic merits of processing the eight inorganic products shown have not been proven. The products should be viewed as representative of those whose economic justification will be established by Spacelab experiments.

Responsible agency - NASA

Assumptions/ground rules/limitations - The space processing facility was assumed to be a free-flying satellite constructed around a ground-modified expended Shuttle external tank (ET). Design data and specifications are discussed in another section of this report.

- *Space operations* - See following space processing opportunity.
- *Ground operations* - See following space processing opportunity.

Cost data - Cost estimates for the development of the facility were derived primarily from CER's applied to preliminary design specifications.

- *Non-recurring cost ($M)*

Space segment	213.2
Ground segment	5.0
Transportation (not applicable)	—
Total	218.2

*In this study NASA funds were assumed, however, in this or any of the opportunities, commercial funding may be forthcoming and precipitate a joint or strictly commercial venture.

- *Annual operating cost* - Not applicable

System acquisition funding requirements (1977 $M)

TOTAL	1981	1982	1983	1984	1985
218.2	2.45	53.44	97.43	54.34	10.54

40B. LARGE CRYSTALS
41. SUPER-LARGE-SCALE INTEGRATED CIRCUITS
42. NEW GLASSES
43 HIGH-TEMPERATURE TURBINE BLADES
44. HIGH-STRENGTH PERMANENT MAGNETS
45. CUTTING TOOLS
46. THIN-FILM ELECTRONIC DEVICES
47. CONTINUOUS RIBBON CRYSTAL GROWTH

Potential market area - These anchor opportunities are considered typical of those whose on-orbit production will be found to be economically viable based on Spacelab experiments. Of the 150 space processing experiments compiled by the West German government, it was considered reasonable that five percent would result in the establishment of full-scale processing facilities in orbit.

Responsible agency - Commercial—corporations or consortia would fund production and operation of the facilities.

Assumptions/ground rules/limitations - Each manufacturing facility would be a dedicated free-flyer, based on the external tank. All of the anchor opportunities would require large amounts of energy, even assuming significant recapture of waste heat. Approximately 50,000 lb of material was assumed to be processed annually by each facility.

- *Space operations* - The facilities were assumed to be located in low-inclination earth orbit. Batteries (charged by over-sized solar panels during sunlit passages) were assumed to provide power during earth-shadow passage. Logistics flights were assumed to occur every three months.

- *Ground operations* - A centralized mission control and satellite monitoring facility was assumed. Its costs would be shared by the users. No ground processing costs were assessed against ground operations because it was assumed that the material would enter conventional product streams.

Cost data - Cost estimates were derived primarily by CER's applied to design data. The following cost data apply to each of the eight opportunities:

- *Non-recurring cost ($M)*

Space segment	126.5
Ground segment	10.0
Transportation (six Shuttle flights)	130.8
Total	267.3

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- *Annual operating cost ($M)*

Space segment	21.8
Ground segment	2.0
Total	23.8

System acquisition funding requirements (1977 $M)

OPPORTUNITY NUMBER	TOTAL	1981	1982	1983	1984	1985	1986	1987
40B	262.3	2.94	64.24	117.14	65.32	12.66	—	—
41, 42, 43	267.3	3.00	65.47	119.36	66.57	12.90	—	—
44, 45	267.3	—	3.00	65.47	119.36	66.57	12.90	
46, 47	267.3	—	—	3.00	65.47	119.36	66.57	12.90

48A. SOLAR POWER SYSTEM DEVELOPMENT (NASA PORTION)

Potential market area - Relatively large amounts of solar-derived energy will be required by a number of NASA programs. In addition, several NASA programs will entail the construction of large space structures. Therefore, the cost of development of that portion (minor) of this anchor opportunity, which substantially applies to other NASA programs, was assumed to be borne by NASA. The major portion would be borne by the Department of Energy (see No. 48B).

Responsible agency - NASA

Assumptions/ground rules/limitations - Developments related to the beam machine, which would be required for the construction of several NASA large space structures, were assumed in this anchor opportunity.

- *Space operations* - The space operations consisted of a Shuttle test demonstration flight (assumed to be successful).

- *Ground operations* - No continuing ground operations beyond the development phase were assumed.

Cost data - Cost estimates were derived by analogy to system/costs from in-house studies of the construction of large space structures.

- *Non-recurring cost ($M)*

Space segment		20.0
Ground segment		5.0
Transportation		21.8
	Total	46.8

- *Annual operating cost* - Not applicable

System acquisition funding requirements (1977 $M)

TOTAL	1980	1981	1982	1983
46.8	0.93	19.57	22.16	4.14

48B. SOLAR POWER SYSTEM DEVELOPMENT (DOE PORTION)

Potential market area - The purpose of this anchor opportunity is to develop and demonstrate all of the key technology that would be required in the construction of large solar power systems in geosynchronous orbit. Under the baseline Plan B, this activity needs to be completed before 1987 in order that the decision whether to proceed with the construction of an SPS can be made on sound economic data in 1987.

Responsible agency - U.S. Government agency (Department of Energy)

Assumptions/ground rules/limitations - The SPS was assumed to be photovoltaic and based on the design generated in the Rockwell SPS study. The developmental activities were those identified in that study.

- *Space operations* - Key issues regarding the technical feasibility of constructing an SPS will be resolved by demonstrations on orbit.

- *Ground operations* - Technical and economic feasibility of the microwave-receiving ground station will be demonstrated.

Cost data - Cost estimates were derived from the Rockwell SPS study. The total non-recurring cost of $3000 million was not categorized by space and ground elements; therefore, the breakout is not shown. The "annual operating cost" does not apply because this is essentially a developmental program.

Development funding requirements (1977 $M)

TOTAL	1980	1981	1982	1983	1984	1985	1986
3000	15.04	339.68	726.56	930.24	619.36	306.88	62.24

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49. NIGHT ILLUMINATION (LUNETTA)

Potential market area - This anchor opportunity results in the night illumination of a large number of cities. As a result, large amounts of terrestrial energy (principally oil for electricity generation) are saved and night-time illumination of cities is improved.

Responsible agency - U.S. Government agency (Department of Energy)

Assumptions/ground rules/limitations - The primary justification would be the saving of energy in the U.S. However, once a network of Lunettas is established, it can service foreign cities with little or no additional cost. The basic concept is that presented by Dr. Krafft Ehricke in his May, 1977, paper titled *Space and Energy Sources* and presented at the World Electromechanical Congress in Moscow in June, 1977.

- *Space operations* - The network consists of 24 reflectors in each of five orbits. These would be revisited occasionally for refurbishment and maintenance.

- *Ground operations* - A ground station for network monitoring and control was assumed.

Cost data - Cost estimates used were basically those presented in the paper referenced above.

- *Non-recurring cost ($M)*

Space segment	2,237.0
Ground segment	10.0
Transportation	500.0
Total	2,747.0

- *Annual operating cost ($M)*

Space segment	10.0
Ground segment	10.0
Total	20.0

System acquisition funding requirements (1977 $M)

TOTAL	1987	1988	1989	1990	1991
2747.0	31.26	672.70	1226.53	683.96	132.55

50. MEDICAL AND GENETIC RESEARCH (SPACE BASE)

Potential market area - A large variety of unique pharmaceuticals need to be produced (isolated or purified) in relatively small quantities to meet highly specialized demand. These could be produced in what is basically a research facility.

Responsible agency - U.S. Government agency (Department of HEW)

Assumptions/ground rules/limitations - Isoenzymes (see No. 37) were assumed to be produced on this facility which is attached to the low earth orbit base (see No. 55).

- *Space operations* - The scientists conducting research would likely discover new biological and genetic (recombinant DNA) processes unique to the zero-g environment. In addition, they would process (extract, purify, synthesize) pharmaceuticals such as isoenzymes that are desired by medical researchers on earth. Transportation costs of materials were assumed to be minimal. On-orbit man-hour costs were a major cost element.

- *Ground operations* - A "mission control" center that would direct the research program, prepare materials for space processing, and analyze results was assumed.

Cost data - Costs were estimated by analogy to space base facilities, described and costed in recent space station studies.

- *Non-recurring costs ($M) (1/2 of actual total—see No. 37)*

Space segment	100.0
Ground segment	5.0
Transportation to LEO	11.0
Total	116.0

- *Annual operating cost ($M)*

Space segment	10.0
Ground segment	5.0
Total	15.0

System acquisition funding requirements (1977 $M)

TOTAL	1982	1983	1984	1985	1986
116.0	1.30	28.42	51.80	28.88	5.60

51. SHUTTLE/SPACELAB

Potential market area - The Shuttle and Spacelab will be the initial source of a number of space benefits. Potential space applications/opportunities will be tested and verified prior to their full implementation on dedicated spacecraft. Space-produced materials required in small quantities may be produced indefinitely on Shuttle/Spacelab flights.

Responsible agency - NASA

Assumptions/ground rules/limitations - The Shuttle was assumed to be the basic space logistics vehicle until the development of the HLLV and even then it would remain the basic personnel transporter.

- *Space operations/ground operations* - The cost of Shuttle operations was assessed against the users.

Cost data - Cost estimates were based on data extracted from NASA budget hearings. These did not break out the costs into space and ground segments or transportation. The total non-recurring cost (through 1983) was $2621.6 million.

System acquisition funding requirements (1977 $M)

TOTAL	1980	1981	1982	1983
2621.6	1127.9	777.9	446.9	268.9

52. EXTENDED-DURATION ORBITER/25-kW POWER MODULE

Potential market area - The basic Shuttle has an on-orbit staytime on the order of seven days because of power limitations. This time period is too short for some of the contemplated mission payloads such as those associated with the development of space processing hardware which, in addition, will also require substantial electrical energy. This opportunity focuses on the development of a 25-kW power module that would provide energy for extended-duration Shuttle missions.

Responsible agency - NASA

Assumptions/ground rules/limitations - The 25-kW power module, once deployed, was assumed to remain in orbit as a free-flying satellite or mated to a payload.

- *Space operations* - The Shuttle would rendezvous and dock with the 25-kW power module for extended missions.

- *Ground operations* - The module would have its own mission control center.

Cost data - Cost estimates were based primarily on NASA budget hearing data.

- *Non-recurring cost ($M)*

Space segment		130.0
Ground segment		10.0
Transportation		21.8
	Total	161.8

- *Annual operating cost ($M)*

Space segment		—
Ground segment		10.0
	Total	10.0

System acquisition funding requirements (1977 $M)

TOTAL	1980	1981	1982	1983
161.8	3.20	67.67	76.61	14.32

53. ADVANCED TELEOPERATOR

Potential market area - An advanced teleoperator would be required to emplace and service payloads on the geosynchronous platforms. It would also be highly desirable for construction of the large solar array structures on these platforms.

Responsible agency - NASA

Assumptions/ground rules/limitations - The advanced teleoperator is assumed to have a small propulsion package and be capable of rendezvousing, docking, and emplacing or servicing various payloads while under ground, Shuttle, or space base control. Three teleoperators were assumed to be required.

- *Space operations* - The teleoperator could be recovered by the Shuttle for return to earth.

- *Ground operations* - Mission control would be linked to the teleoperators via TDRS.

Cost data - Cost estimates were derived primarily from teleoperator studies.

- *Non-recurring cost ($M)*

Space segment	150.0
Ground segment	10.0
Transportation (test flight, 1/3 Shuttle)	7.0
Total	167.0

- *Annual operating cost ($M)*

Space segment	—
Ground segment	10.0
Total	10.0

System acquisition funding requirements (1977 $M)

TOTAL	1981	1982	1983	1984	1985
167.0	1.87	40.89	74.58	41.60	8.06

54. GEOSYNCHRONOUS PLATFORM—USA

Potential market area - A geosynchronous platform (GP) is required for housing and supporting up to eight service category payloads. It would be capable of producing 500 kW; in case the 500-kW capability were not attainable by 1986—when the GP is scheduled to become operational—conceptual designs of a smaller (100 kW) platform were generated (see Figure). However, analyses of this platform indicated that its severely reduced capability to support what are considered to be near-minimal operational payloads, when coupled with a significant loss in the economies of scale, make the approach of questionable merit. For example, while the 100-kW version would have only 20 percent of the capability of the basic GP, it would weigh 40 percent as much, resulting in the cost of its support services per unit of energy delivered being almost three times that of the 500-kW GP. Consequently, the 100-kW version was not considered in the programmatic analysis.

Responsible agency - NASA

Assumptions/ground rules/limitations - Because common technology would be required for both the geosynchronous platform and for the SPS feasibility demonstratons, it was assumed that the Department of Energy cost-shared this development (see No. 48b). The DOE portion was assumed to cover the DDT&E costs of the platform. A description and specifications of the platform are presented in another section of this report.

- *Space operations* - The platform was assumed to be constructed in low earth orbit, initial payloads attached, and the platform transported to geosynchronous orbit by three solar electric propulsion systems (SEPS). It was assumed to contain laser-powered data transmission systems for communications with the European/African GP and with the Asian GP that are assumed to follow in several years. Each payload housed would be assessed an amount sufficient to recover the cost of the GP within 10 years, plus yield a 10-percent annual return. Several GP's might be required to accommodate all of the payloads.

- *Ground operations* - Mission Control would monitor and regulate the platform performance.

Cost data - Cost estimates were derived primarily from CER's applied to design specification data.

- *Non-recurring costs ($M)*

Space segment	155.7
Ground segment	10.0
Transportation (4 Shuttles, 3 SEPS, 1 IUS +)	115.7
Total	281.4

- *Annual operating cost ($M)*

Space segment	—
Ground segment	10.0
Total	10 0

System acquisition funding requirements (1977 $M)

TOTAL	1981	1982	1983	1984	1985
281.4	3.15	68.92	125.58	70.08	13.57

55. LOW EARTH ORBIT BASE

Potential market area - A low earth orbit base would be the focal site for (1) orbital construction of large structures, (2) medical and genetic research (see No. 50), (3) space processing and materials research, and (4) processing of data from polar satellites prior to transmission to earth.

Responsible agency - NASA

Assumptions/ground rules/limitations - The low earth orbit base was assumed to be similar to the space station design generated in the McDonnell Douglas and Grumman space station studies completed in 1977.

- *Space operations* - The initial base was assumed to consist of a habitation module with accommodations for up to nine personnel and with on-board computers for data processing. Considerable legacy was assumed from Skylab and Spacelab. Additional modules were assumed to be appended to the initial base as their needs and justifications evolved.

- *Ground operations* - Existing facilities for mission control of manned space operations were assumed to be modified for support of the space base. Four Shuttle flights per year were assumed to be required for crew rotation and material exchange/resupply.

Cost data - Cost estimates were derived from data in the McDonnell Douglas and Grumman space station studies.

- *Non-recurring cost ($M)*

Space segment	292.0
Ground segment	10.0
Transportation	21.8
Total	323.8

- *Annual operating cost ($M)*

Space segment	87.2
Ground segment	5.0
Total	92.2

System acquisition funding requirements (1977 $M)

TOTAL	1981	1982	1983	1984	1985	1986
323.8	2.33	51.97	109.07	101.39	49.24	9.80

56. POLAR PLATFORM A

Potential market area - The polar platform provides common housekeeping functions to several payloads at a considerable cost saving. The platform is stationed in a sun-synchronous orbit. By having several operational payloads, each operating in a different combination of spectral frequencies while viewing a given area simultaneously, synergistic benefits can result. Unique combinations of spectral responses can be extracted from the various payloads to yield data on resources other than those being surveyed.

Responsible agency - NASA

Assumptions/ground rules/limitations - The platform was assumed to be in an orbit that repeats every 18 days. This repetition interval was too long for many operational missions (e.g., crop forecasting). Two other platforms (see No. 59 and No. 65) were assumed to be emplaced at one-year intervals—thereby achieving a six-day repeat coverage. A ten-year life was assumed. The platform users would be assessed a charge sufficient to recover all costs in ten years plus a 10-percent annual return.

- *Space operations* - Data from the polar platform was assumed to be relayed via TDRS to ground stations initially and, eventually, to the space base for preliminary processing. The Shuttle could deliver payloads directly to the platform.

- *Ground operations* - Platform operations were assumed to be monitored and regulated by a dedicated mission control.

Cost data - Cost estimates were generated by analogy to the geosynchronous platform subsystem costs.

- *Non-recurring cost ($M)*

Space segment	71.7
Ground segment	10.0
Transportation	21.8
Total	103.5

- *Annual operating cost ($M)*

Space segment	—
Ground segment	5.0
Total	5.0

System acquisition funding requirements (1977 $M)

TOTAL	1983	1984	1985	1986
103.5	2.05	43.28	49.01	9.16

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57. GEOSYNCHRONOUS PLATFORM—EUROPE AFRICA

Potential market area - This is a European/African version of the geosynchronous platform that was developed to service the U.S. (see No. 54).

Responsible agency - Foreign government consortium.

Assumptions/ground rules/limitations - See No. 54.

Cost data - See No. 54.

System acquisition funding requirements (1977 $M)

TOTAL	1983	1984	1985	1986	1987
281.4	3.15	68.92	125.63	70.08	13.57

58. LUNETTA DEMONSTRATION

Potential market area - Prior to the acquisition of the Lunetta, a demonstration version will be tested to validate its technological feasibility, generate efficiency data, and to ascertain public reaction.

Responsible agency - NASA

Assumptions/ground rules/limitations - The demonstration version of Lunetta is transportable and deployable by one Shuttle flight. It was assumed to be a full-scale version of a single orbital reflector and would be 800 feet on a side.

- *Space operations* - A stabilization and control package (off the shelf) was assumed to permit ground control during the test period. A low-thrust propulsion package (also off the shelf) was assumed to be an integral part of the reflector. The propulsion unit (approximately 5500 kg) would raise the 3000-kg reflector unit from low earth orbit to its contemplated operational altitude of 4200 km (3-hour orbit). Performance tests would be performed at intermediate altitudes.

- *Ground operations* - The demonstration Lunetta would be oriented by ground control.

Cost data - Cost estimates were derived by analogy to other spacecraft cost data.

- *Non-recurring cost ($M)*

Space segment		50.0
Ground segment		10.0
Transportation		21.8
	Total	81.8

- *Annual operating cost* - Not applicable (test program)

System acquisition funding requirements (1977 $M)

TOTAL	1984	1985	1986	1987
81.8	1.62	34.22	38.71	7.25

59. POLAR PLATFORM B
60. POLAR PLATFORM C

Potential market area - These two platforms are identical with Polar Platform A (See No. 56). They reduce the interval between repeat overflights from 18 days to 6 days.

Responsible agency - NASA

Assumptions/ground rules/limitations - Platforms B and C were assumed to follow Platform A by one and two years, respectively (see No. 56).

Cost data - Cost estimates were derived by analogy to the geosynchronous platform cost data. The following data apply to Platform B as well as C.

- *Non-recurring cost ($M)*

Space segment		43.0
Ground segment (acquired in No. 56)		—
Transportation		21.8
	Total	64.8

- *Annual operating cost ($M)*

Space segment		—
Ground segment		5.0
	Total	5.0

System acquisition funding requirements (1977 $M)

	TOTAL	1984	1985	1986	1987	1988
• *Platform B* -	64.8	1.28	27.10	30.68	5.74	—
• *Platform C* -	64.8	—	1.28	27.10	30.68	5.74

61. GLOBAL WEATHER AND RESOURCE BASE

Potential market area - Even marginal improvements in weather forecasting capability could yield sizable benefits. The Global Weather and Resource Base operates in conjunction with the Global Effects Monitoring payloads (No. 29), and with data from other sensors to furnish a basis for longer range and more accurate weather forecasts.

Responsible agency - U.S. Government agency (Department of Commerce)

Assumptions/ground rules/limitations - The base was assumed to consist of two modules—a habitation module and an equipment module. Under normal conditions, it would not be manned continuously but, rather, visited periodically. While some data would be telemetered to earth, other data would be physically recovered and returned to earth for analysis (e.g., high-energy solar proton-detecting emulsions).

- *Space operations* - The base was assumed to be in a 400 to 600 km altitude, 55-degree inclination orbit. Its variety of sensors and frequency of overflight would enable it to tie together data from other sources. Its telemetered data were assumed to be relayed via TDRS to a ground station or to the space base for processing. The base was assumed to be revisited via the Shuttle four times per year.

- *Ground operations* - A ground facility would be required for control of the base during its unmanned periods.

Cost data - Cost estimates were derived by analogy to modules described and costed in the McDonnell Douglas and Grumman space station studies which were completed in 1977.

- *Non-recurring cost ($M)*

Space segment	500.0
Ground segment	10.0
Transportation	43.6
Total	533.6

- *Annual operating cost ($M)*

Space segment	87.2
Ground segment	10.0
Total	97.2

System acquisition funding requirements (1977 $M)

TOTAL	1985	1986	1987	1988	1989
553.6	6.21	135.59	247.22	137.86	26.72

62 GEOSYNCHRONOUS PLATFORM—ASIA

Potential market area - This platform is similar to the U.S. (No. 56) and European/African (NO.57) platforms, but services the Asian area.

Responsible agency - Foreign government consortium

Assumptions/ground rules/limitations - See No. 54.

Cost data - See No. 54.

System acquisition funding requirements (1977 $M)

TOTAL	1985	1986	1987	1988	1989
281.4	3.15	68.92	125.68	70.08	13.57

63. LOW-THRUST OTV (SEPS)

Potential market area - A low-thrust orbital transfer vehicle (OTV) will be required to propel large, relatively fragile structures that have been erected or deployed in low earth orbit to their destinations in geosynchronous orbit. The Solar Electric Propulsion Stage (SEPS) is one of the leading candidates for the low-thrust OTV.

Responsible agency - NASA

Assumptions/ground rules/limitations - The SEPS configuration was assumed to be basically that generated by the Space Division of Rockwell International and documented in *Concept Definition and Systems Analysis Study for a Solar Electric Propulsion Stage* (Contract NAS8-30920), February 3, 1975.

Cost data - Cost estimates were based on data from the SEPS studies.

- *Non-recurring cost ($M)*

Space segment	193.2
Ground segment	10.0
Transportation	21.8
Total	225.0

- *Annual operating cost ($M)*

Space segment (borne by user)	—
Ground segment	10.0
Total	10.0

System acquisition funding requirements (1977 $M)

TOTAL	1980	1981	1982	1983	1984
225.0	2.52	55.10	100.50	56.03	10.85

64. HLLV-1 (SHUTTLE WITHOUT ORBITER)

Potential market area - A payload-to-orbit capability exceeding that of the Shuttle will be required in the late 1980's. The Heavy-Lift Launch Vehicle (HLLV) is based on evolutionary growth of the Shuttle hardware, and consists of a cargo pod in place of the orbiter.

Responsible agency - NASA

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Assumptions/ground rules/limitations - The data assumed—both performance and cost—were extracted from the Space Division's *Shuttle Growth Study* (Contract NAS8-32015), May 1977, Volume V.

- *Space operations* - The HLLV design selected would have a payload-to-orbit (300 km, 28.5 degrees) capability of 233,000 lb (106,000 kg), at a cost of $12.83 million per flight, or $55 per pound ($121 per kilogram).

- *Ground operations* - A mission control facility would be required. Flights would be unmanned.

Cost data - Cost estimates were derived from data in the aforementioned study report and from the study costing personnel.

- *Non-recurring cost ($M)*

Space segment	1950.0
Ground segment	10.0
Transportation (test flight)	21.8
Total	1981.8

- *Annual operating cost ($M)*

Space segment (borne by users)	—
Ground segment	10.0
Total	10.0

System acquisition funding requirements (1977 $M)

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TOTAL	1985	1986	1987	1988	1989
1981.8	22.22	485.39	885.05	493.51	95.63

65. OTV (LARGE CHEMICAL)

Potential market area - Substantial payloads will need to be delivered more quickly to geosynchronous orbit than is possible with the SEPS.

Responsible agency - NASA

Assumptions/ground rules/limitations - The OTV specification and costs assumed were based on data obtained from the NASA Technical Memorandum, NASA TM X-73394, *Orbit Transfer Systems with Emphasis on Shuttle Applications —1986-1991* (April 1977).

- *Space operations* - The all-propulsive version was assumed. It would have a geosynchronous orbit round-trip capability of up to 3600 kg (8000 lb) in the dual-stage-per-Shuttle mode; this might be sufficient for transporting a manned module to geosynchronous orbit and back.

- *Ground operations* - A mission control facility would be required. The OTV would be recovered for ground refurbishment.

Cost data - Cost estimates were derived from data extracted from the aforementioned report.

- *Non-recurring cost ($M)*

Space segment	600.0
Ground segment	10.0
Transportation (test flight)	21.8
Total	631.8

- *Annual operating costs ($M)*

Space segment (borne by users)	—
Ground segment	10.0
Total	10.0

System acquisition funding requirements (1977 $M)

TOTAL	1981	1982	1983	1984	1985	1986
631.8	(19.14) R&D	4.55	101.42	212.77	197.8	96.08

RECOMMENDED PLAN SUMMARY AND CONCLUSIONS

Annual funding requirements developed for each recommended opportunity were aggregated by year for each of the four funding source categories; these data are shown in Figure 109. Shuttle/Spacelab funding was omitted to permit focusing on new opportunities. The 1983 peak in other U S. Government funding

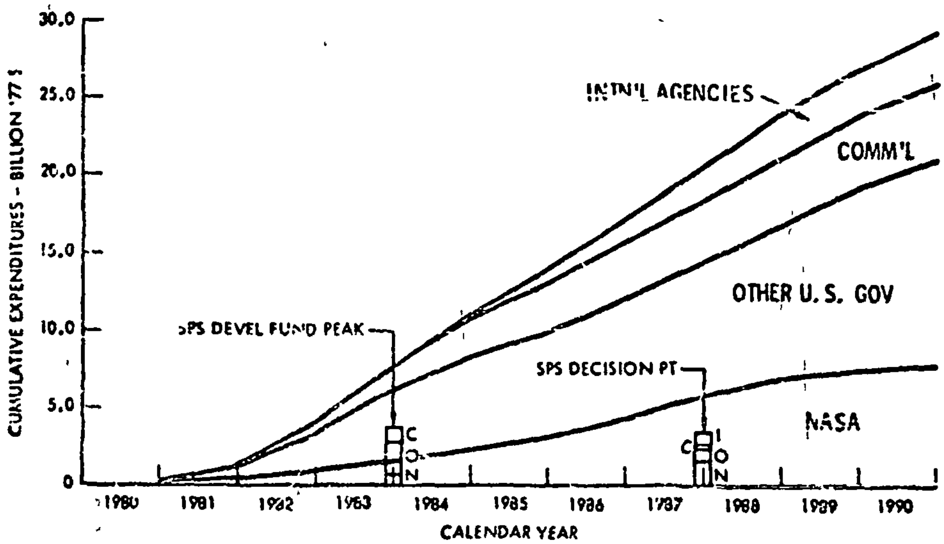

Figure 109. Cumulative Expenditures for Space Industrialization

is due primarily to No. 2, Electronic Mail ($779.04 million); and No. 48B, Solar Power System Development ($930.24 million). The NASA funding requirement peak in 1987 is due largely to No. 64, HLLV-1 ($885.05 million); and to No. 32, Microwave Radiometer ($282.04 million) acquisitions.

Although NASA may not be directly funding a major portion of the opportunities described, it could be responsible for managing most of the development programs for the non-NASA opportunities. NASA already has experienced personnel; other agencies would have to acquire space hardware development teams for what are essentially single developments. Substantial savings and increased efficiencies would result from the use of existing NASA personnel and teams. Immediate action should be initiated to alert other government agencies of the potential benefits from many of these opportunities in order to preclude foreign inroads into the advanced technology of the aerospace market. If foreign agencies capture a significant technological lead and demonstrate proficiency in the development of space hardware, it will become increasingly difficult to direct foreign space business to the United States.

No credence should be placed in the downward slope of the funding curves in 1988, 1989, and 1990. This results because no second-generation developments were included. They would have required highly speculative assumptions and funding requirements that would have compromised the validity of the funding aggregates shown. The recommended opportunities will spawn additional space ventures, unforeseen today, that will reverse the downward slopes. Moreover, the ten-year on-orbit lifetimes of many opportunties will be nearing termination and therefore will necessitate system replacement or refurbishment.

The 65 recommended opportunities were analyzed to determine the Shuttle traffic to be generated annually by space industrialization. Figure 110 shows the number of Shuttle flights (by year) that would be necessary to implement the recommended opportunities. The data are conservative because they assume all-success programs. They show that in the second half of the 1980's, approximately 40 flights per year will be required to support just the recommended space industrialization opportunities.

While the actual cost of some of the service opportunities may appear high, the number of persons that could benefit from the service is very large. Consequently, the annual per capita "opportunity availability" cost is low. For example, the annual per capita cost of having the *opportunity* to make use of the service offered by a pocket telephone or direct-broadcast TV is on the order of $0.33. The annual per capita costs of some representative opportunities are shown in Table 14. These are opportunity availability costs, and do not include the costs of actually using the service if desired.

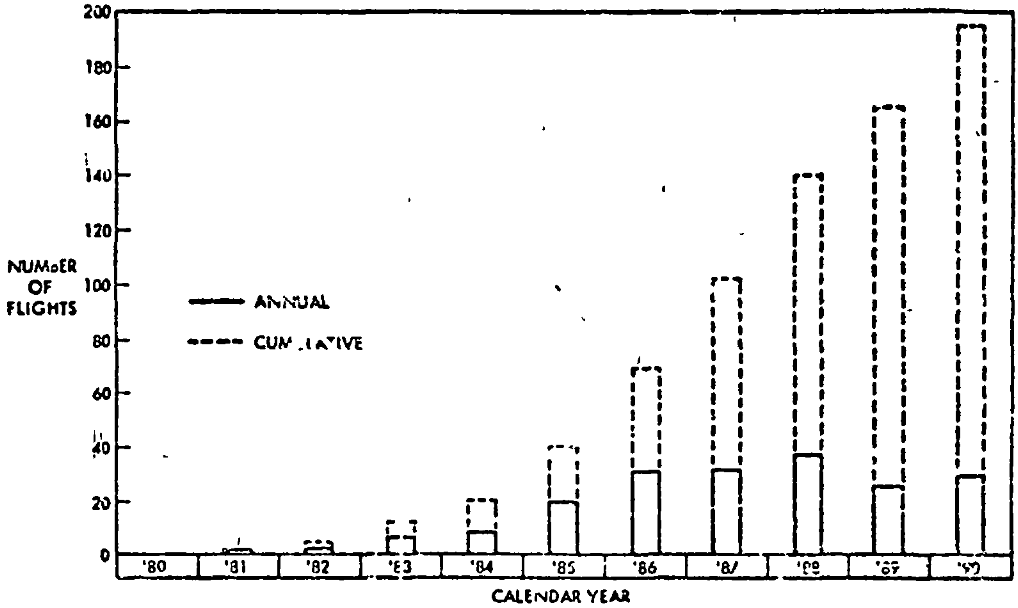

Figure 110. Shuttle Traffic Schedule—Plan B (Space Industrialization Only

Table 14. Annual Per Capita Costs of Representative Opportunities (Based on Capital Recovery in 10 Years at 10% Per Year)

	Anchor Opportunity	Cost Per Capita Per Year (USA)[1]
3	Pocket telephones	$ 0.33
4	Direct broadcast education (5 channels)	$ 0.32
11	World medical advice center	$ 0.20
14	Medical aid and information	$ 0.37
21	National information service (Library of Congress)	$ 0.39
28	Crop measurement	$ 0.23

[1]Costs shown are system costs and do not include user charges.

PROGRAMMATIC ANALYSIS OF ALTERNATIVE PLANS

PROGRAMMATIC ANALYSIS OF ALTERNATIVE PLANS

INTRODUCTION

During Part I of the study, four distinct program plans (scenarios) were developed. Plan A assumed that in 1987 the decision would be made to proceed with the immediate acquisition of an SPS by one of two alternative approaches. In Plan A_1, a lunar base and material processing facility would be constructed and the SPS produced from basically lunar materials. In Plan A_2, the SPS would be constructed from terrestrial materials. Plan B assumed that in 1987 the decision was made not to build an SPS. Under Plans A_1, A_2, and B it was assumed that the Department of Energy would fund those aspects of the geosynchronous platform development that were directly applicable to the SPS technology development program. Plan C assumed that all SPS activity would be halted in 1982, and that NASA would bear the full cost of developing the geosynchronous platform. A drawing of such a platform is shown in Figure 111 (Dwg. 78255-002).

At the conclusion of Part I, Plan B was chosen as the baseline recommended plan for detailed analysis during Part II. The previous section reported on the analysis and findings pertaining to Plan B. In this section the programmatics of Plans A_1, A_2, and C will be examined.

SCOPE AND LIMITATIONS/APPROACH

The 65 recommended opportunities are essentially common to all plans. A cursory analysis was made to determine key incremental programs necessary to implement Plans A_1 and A_2, and gross cost estimates were generated on these items. The cost estimates for the initial years of SPS acquisition were spread from 1988 through 1990. Plan C was basically a re-allocation of resources.

TECHNICAL DATA

Plan A_1 (Lunar)

The major programs included in this plan were (1) a lunar base, (2) lunar industrial (material processing) facilities, (3) an earth-to-moon transport vehicle with a manned capability, (4) a lunar orbit-to-surface-to-orbit Shuttle, and (5) the SPS construction including a ground station. The total nonrecurring cost resulting in the construction of one SPS was estimated to be on the order of \$47 billion (1977 \$). During the initial three years, the funding requirements would be (1977 \$M):

	1988	1989	1990
NASA	629.0	2943.0	4488.5
U.S. Government agency (Department of Energy)	121.5	742.5	1816.2

ORIGINAL PAGE IS OF POOR QUALITY

Plan A_2 (Terrestrial)

The key programs included in this plan were (1) a large, manned orbital transfer vehicle, (2) a single-stage-to-orbit heavy-lift vehicle (Star-Raker), and (3) the SPS itself including a controlling ground station. The total nonrecurring cost for building one SPS was estimated to be $41.5 billion. The funding requirements for the initial three years (1977 $M) would be:

	1988	1989	1990
NASA	175.2	944.3	1831 4
U.S. Government agency (DOE)	135.0	825.0	1878.0

Plan C

In this plan, NASA funding was increased to cover the share of the cost of the geosynchronous platform development, assumed borne by DOE in Plan B ($187.5 million).

A comparison of the funding requirements under each of the four plans is shown in Figure 112. SPS funding (DOE) is shown added to the Plan B NASA funding. Shuttle and Spacelab funding has been omitted in order to focus on the other space industrialization funding requirements from 1981 through 1984. The recommended opportunities were found to be common to all plans until 1987; therefore, the bottom curve applies to Plans A_1, A_2, and B between 1980 and 1987.

PROGRAMMATIC ANALYSIS SUMMARY AND CONCLUSIONS

The SPS support level and technological success constitutes the key determinant governing implementation of the alternative plans. Several indicators should be monitored to track the likelihood of implementation of SPS. Among these are the SPS development funding levels, success of fusion research, foreign interest in SPS (potential for cost sharing), and exacerbation of pollution from fossile fuels along with deleterious climatic impacts.

Conceivably, events could accelerate the 1987 SPS decision by one or even ten years. Recently reported findings of *metallic* titanium, silicon, and aluminum in the Soviet Luna 24 core sample could favor earlier schedules for lunar missions than those shown in the baseline plan. Confirmation of metallic deposits from these missions would favor implementation of Plan A_1. On the other hand, UN decisions strongly opposing utilization of lunar resources for national purposes would tend to favor Plan A_2. Reduction in SPS development funding or cancellation of the currently planned SPS activities would favor adoption of Plan C.

Events during the next three to five years will strongly indicate what the 1987 decision will be.

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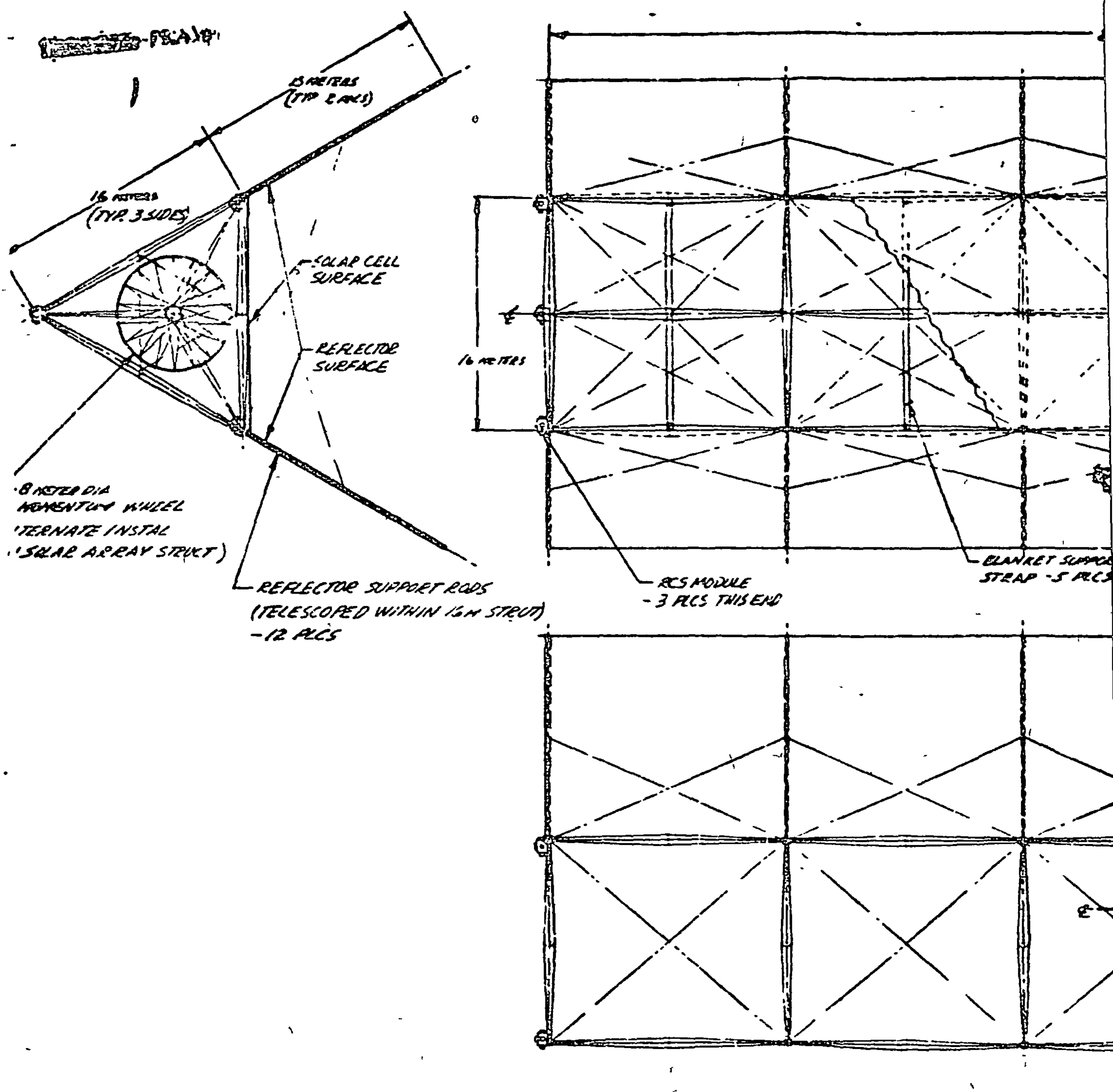

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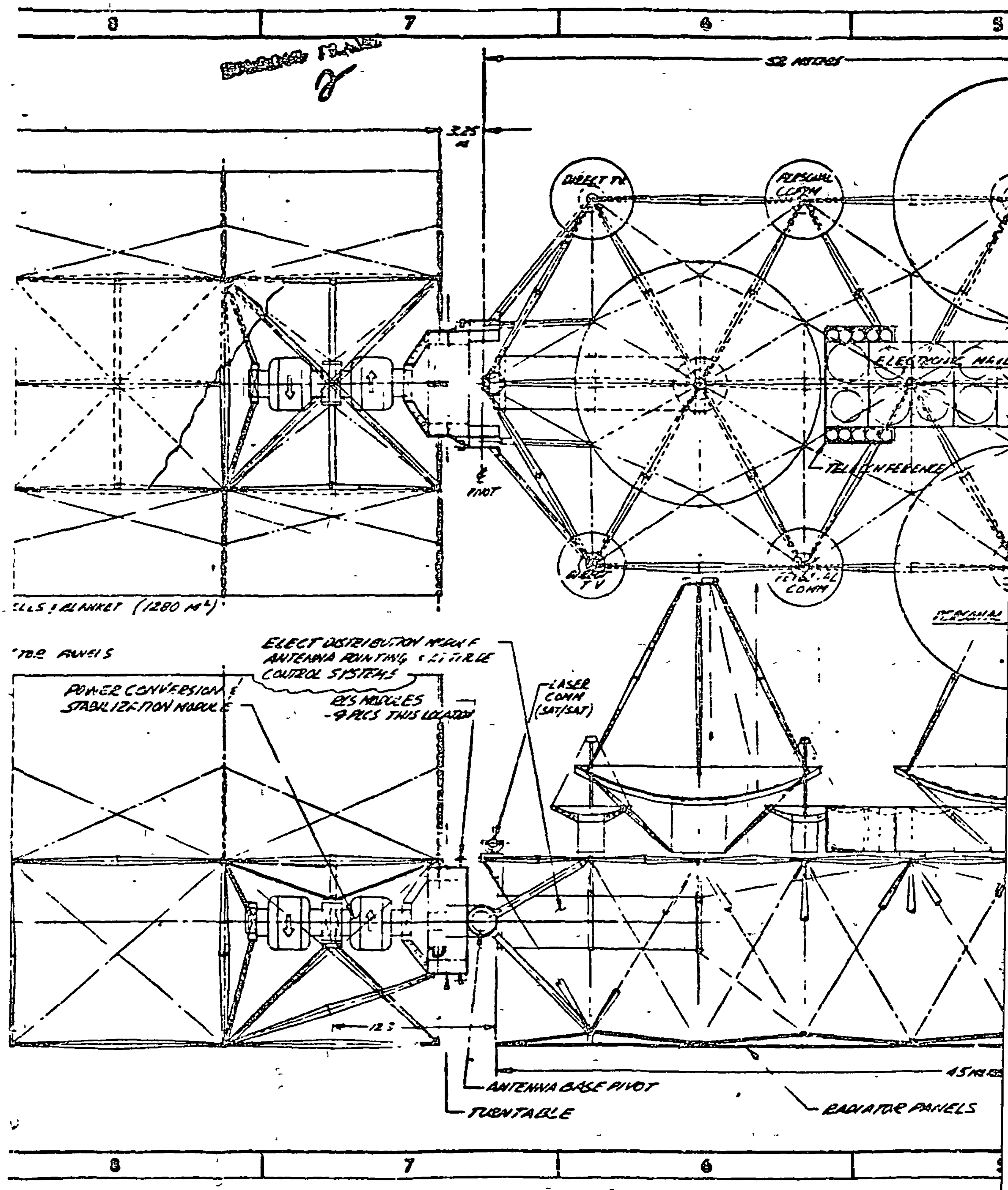

52 METERS
3.25 M
DIRECT TV
PERSONAL COMM
ELECTRONIC MAIL
TELECONFERENCE
PIVOT
TV
COMM
ELECT DISTRIBUTION MODULE ANTENNA POINTING & ATTITUDE CONTROL SYSTEMS
POWER CONVERSION & STABILIZATION MODULE
RCS MODULES - 4 PCS THIS LOCATION
LASER COMM (SAT/SAT)
ANTENNA BASE PIVOT
TURNTABLE
RADIATOR PANELS

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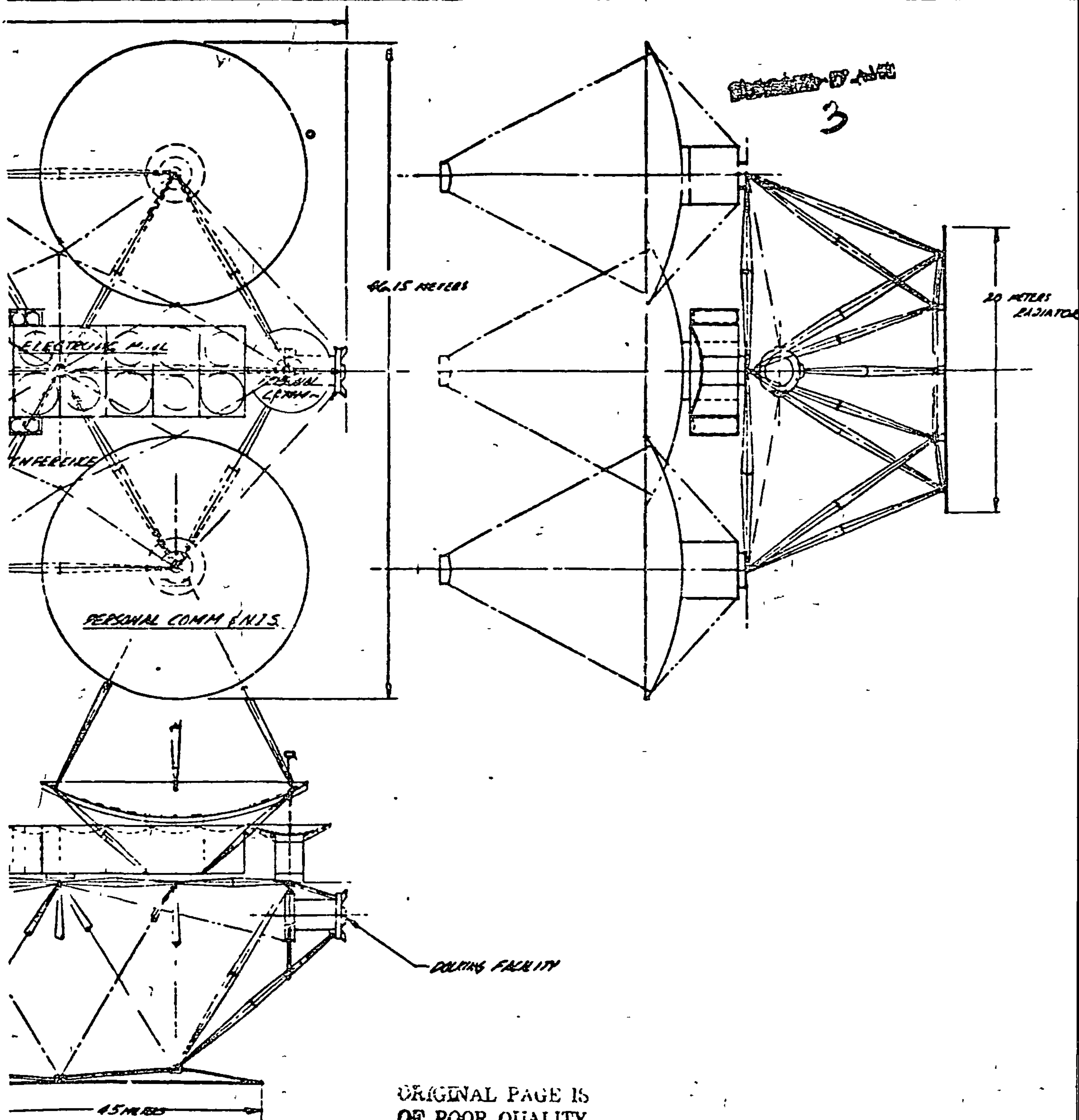

3
46.15 METERS
20 METERS
RADIATOR
ELECTRONIC MAIL
INFERENCE
PERSONAL COMM UNITS
DOCKING FACILITY
45 METERS
ATOR PANELS

5
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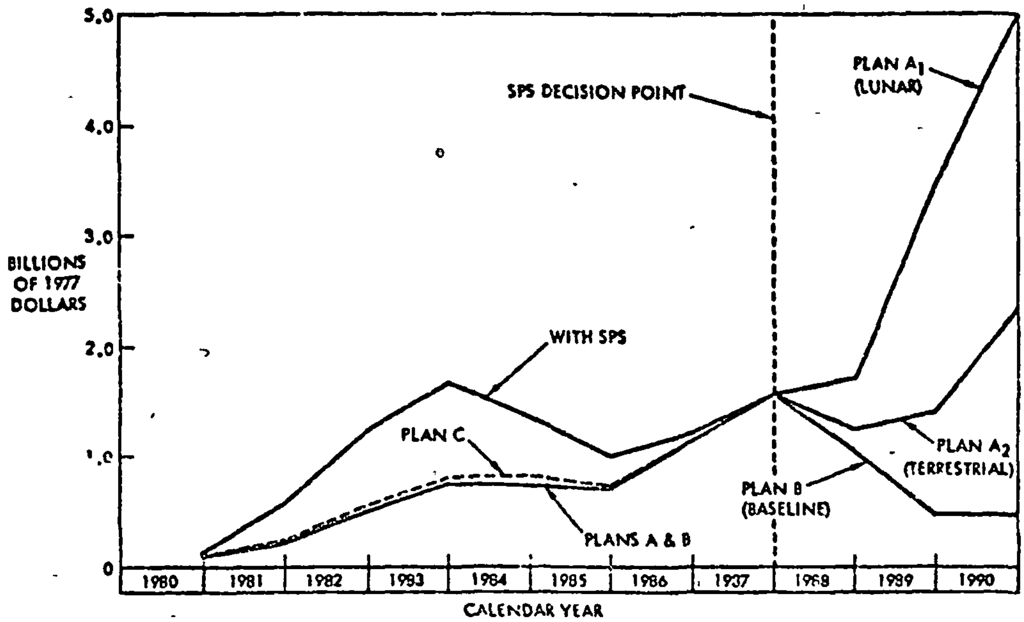

Figure 112. Comparative Annual Funding Schedule (NASA)
(Space Industrialization Only)

Geosynchronous Platform
Information Systems Market Analysis
Global Space Benefits Forecasting
Lunetta
Solar Electric Propulsion
Made-in-Space Products
Large Space Structures
Solar Photovoltaic Space Power Systems
Solar Photovoltaic Technology

SUPPORTING RESEARCH AND TECHNOLOGY

SUPPORTING RESEARCH AND TECHNOLOGY

The following are items of supporting research and technology recommendations per Data Requirement SE-243B. The nature of this study is such that the SRT items are generally system studies or technology area studies which would, in turn, yield specific items of technology needed to support that particular objective.

GEOSYNCHRONOUS PLATFORM

Status

A quantium jump (over current exponential expansion) in communication services is provided by the Geosynchronous Platform. A vigorous pace of technology development is indicated, but no breakthroughs are required.

Justification

The use of communications satellites at GSO is expanding expotentially world wide. The beneficiaries on earth can proliferate as the size and cost of ground stations comes down. If major services such as pocket telephones and direct broadcast TV can be provided with ground units of a few hundred dollars each or less, than a great number of people would benefit.

Technical Plan

Objective

To develop a design for a large, general purpose platform located at GSO that provides a dramatic increase in benefits to earth at a lower overall cost.

Technical Approach

In the next few years, communication satellites in GSO will proliferate, providing many services to businesses and countries with moderately priced ground stations. The quantum jump beyond that is to provide services directly to individuals via ground units that are affordable by virtually everybody in developed countries and to a large number of people (millions) in developing countries. There are many unresolved questions, the most important of which are:

1. Since the *easiest* frequencies get used up first by those who can afford to be first, what is the proper approach to frequency allocation where the objective is major benefits to millions or billions of people?

2. Since the services provided will become increasingly vital, what is the best approach to reliability, updating, etc.: small satellites with an on-orbit spare designed for no maintenance; a large GP with sophisticated teleoperators (Telecommunicated Astronaut) on board; or manned sortie maintenance and updating?

3. What is the optimum transition from current practice and when should this transition occur?

In the study of a Geosynchronous Platform the following specific task subjects should be considered:

- Design
- Sizing
- Maintenance and Updating Methods
- Services Provided
- Growth Policy
- International Usage and Financing Policy
- Services Provided
- RF Band and Bandwidth Utilization
- Ground Systems Costs
- Commercial Revenues
- Advantages over Proliferation of Small Satellites
- Synergism with Other Space and Ground Systems
- Overall Benefits
- Problems and Opposition Expected
- Cost

Resource Requirements

An initial study of approximately $500K is warranted. Beyond that, a major Geosynchronous Platform would cost approximately $600M through the first operational amount.

Target Schedule

Our study indicated that this is the best investment for mankind of all opportunities considered. Therefore, it should proceed at a rapid pace with operational status by about 1986.

INFORMATION SYSTEMS MARKET ANALYSIS

Status

The original NACA and the NASA has had the charter to conduct research and development in specific areas benefiting the national interest. In the information systems area, the NASA tendency has been to withdraw rather than lead. It could well be that this withdrawal comes from an expanding market of unprecidented importance and at a time of unprecidented need for the United States to find areas of relief in balance of payment deficits.

Justification

For the first time in this century, the U.S. finds itself with no clear world marketplace leadership in any area (except perhaps for agriculture). Our balance of payments deficits are gigantic and the old proud term *sound as a dollar* is now a joke. With imaginative leadership, we could do much toward satisfying world needs and at the same time improve our own future by better penetration of the world market in information management. Space has a major role in such an endeavor.

Technical Plan

Objective

To determine if NASA should re-enter the information systems technology development field in a big enough way to be a major factor in the ability of United States companies to penetrate this market.

Technical Approach

This would be an in-house effort by a blue ribbon NASA committee, aided by consultation with industry.

POLAR PLATFORM

Status

Individual payloads not necessarily associated with the primary mission of the spacecraft are routinely integrated into satellites and placed into orbit. However, the piggybacked payloads are usually simple in terms of power requirements, size and data generated. The polar platform would need to be capable of housing several large, primary payloads. A significant portion of the technology would have been developed in support of the geosynchronous platform that would precede the polar platform by approximately one year.

Justification

Several operational (as opposed to developmental) missions have been identified that require acquisition of data from multiple sensors in a sun synchronous orbit. By incorporating these payloads on a common platform, the cost of the housekeeping functions can be shared by the payloads and each can participate in the economics of scale. Additionally, an important benefit would be the availability of data from a combined total of several dozen sensors, all recording simultaneous impressions of a common scene. Extrapolating from results achieved by computer manipulation of Landsat A and B data, the synergism thus created would undoubtedly provide unanticipated data on other valuable earth resources than those being surveyed. The simultaneous relay of large amounts of data (via TDRS) would require technological advances.

Technical Plan

Objective

To develop a design for a general purpose polar platform that would be placed in sun-synchronous orbit and provide housekeeping support to several discrete observational payloads at a substantial cost savings over using an independent satellite per payload.

Technical Approach

Several different observational (sun-synchronous) missions appear meritorious. Each could be implemented independently. However, the use of a common platform would provide two major benefits. First, economics of scale would enable several payloads of sensors to be supported at a lower cost. Second, by having all of the sensors in the various payloads simultaneously viewing the identical scene, analyses of the synergistic results could enable the extraction of data well beyond that which would be furnished by the sum of the individual, unsynchronized payloads. Acquisition of data from diverse sensors in the various payloads could eliminate the need for additional dedicated payloads.

Key emphasis in the proposed work should focus on three interrelated technology issues:

1. Level of Modularization - Should entire payloads be designed as single, detachable modules or should individual sensors be modularized.

2. Data Compaction and Transmission - How should the copious data generated be handled? It will need to be relayed via TDRS. Can radio frequencies handle it or would laser frequencies be required? If radio, then at what frequencies? If laser - to where? Space base? Earth station? Laser alteration/distortion through clouds?

3. Sensor Cooling - Certain sensors need to be cooled to cozogenic temperatures for efficient operation. Should cooling be a housekeeping (i.e., platform) function or should each payload satisfy its own sensor cooling requirements.

Analysis and resolution of the above interrelated issues would constitute the initial task of the proposed effort. The second task would focus on preliminary design of a *typical* platform with particular emphasis on weight because of the limited Shuttle weight capability to sun-synchronous orbit. Included in the design task would be considerations of payload/sensor replacement, platform growth, and on-orbit maintenance. In the third and final task an economic evaluation would be made that would compare the merits of the general purpose platform over the conventional individual, dedicated satellite approach. Also in this task, various methods would be devised for assessing the platform users for the platform acquisition and operating costs.

Resource Requirements

The preliminary design study described would require approximately $350,000 and one year to perform. To develop and construct the Polar Platform would require an estimated $70 million (plus ground facilities and launch costs) and would require approximately three years to build (excluding payloads).

Target Schedule

If the anticipated benefits of a general purpose polar platform are confirmed by the proposed study, then its construction should receive high priority. The data to be generated by the several earth observational payloads that would be carried aboard the polar platform has an urgency that carries over to the construction of the payloads and, hence, to the platform for carrying the payloads. Consequently, the polar platform should be scheduled to be operational by 1987.

GLOBAL SPACE BENEFITS FORECASTING

Status

The creation of wealth and betterment of mankind's fortune, using space, is widely accepted in principle, but confusing in specifics.

Justification

There is increasing public dialogue and interest in the high frontier of space. Evidences of this interest range from pure fiction, like *Star Wars*, through colonization on down to the reality of operational COMSATS. This public dialogue extends into the Office of Management and Budget and Congress, who are trying to separate real and beneficial possibilities from unrealistic dreams.

Technical Plan

Objectives

Conduct continuing study that encompasses a global multi-discipline and futuristic outlook complied with realistic knowledge of technology, systems, schedules, and costs.

Technical Approach

Conduct studies that go across the board of future possibilities to keep valid data flowing to an interested public media, congress, etc. The study should attempt to balance near and far objectives and emphasize people oriented benefits. Realistic costs should be developed for specific, promising alternatives and communicated in terms of percentage of GNP, expendatures in other areas, etc. Wide participation of experts both within the aerospace field and outside, but potentially related fields should be developed using consultants, working groups, symposium participation, etc. Results should be freely disseminated to both national and world audiences and the resulting dialogue made available to NASA in formulating NASA policy.

LUNETTA

Status

There has been virtually no disciplined, funded studies to either confirm the promise of beneficial uses on reflected light or dispute their practicality. It is a major technological step, but not a giant one, i.e., more like another of the century series aircraft (F-100, 101, etc.), rather than an Apollo sized endeavor.

Justification

As the population expands, the major metropolitan areas of the world will grow. Although energy is scarce and expensive these cities must have light. It is possible that major savings in conventional energy usage and lighting system costs can occur by using Lunettas rather than conventional lighting techniques.

Technical Plan

Objective

To develop a design for a set of orbiting reflectors that provide the lighting needs of most of the major cities of the world.

Technical Approach

As we develop large space structures for a multitude of reasons, we want to move toward systems that work with cheaper and cheaper ground units so that even larger segments of the population can directly benefit. The Lunetta is nearly the ultimate of this approach — nothing is required of the recipients except their eyes. The best utility of Lunetta is also its drawback: The more the service is provided around the globe the more cost effective it becomes, but the more difficult it is to implement. Certainly the system would be designed to not provide light where it is not wanted by the majority in that location, but there will undoubtedly be people there also that object to it. Also, the sharing of cost between rich and poor cities and the value of light being globally available for major emergencies makes the funding arrangements difficult. Therefore, the key task that should be undertaken is the overall merit of the idea versus its cost and social problems. Specific tasks would include:

- Design
- Size Optimization
- Construction and Repair Methods
- Effectiveness
- Public Acceptance
- Economics

- Relationship to SPS and Other Large Structures Developments
- International Financing
- Environmental Effects
- Cost

Resource Requirements

An initial merit study would cost approximately $300K. Implenentation of a global system would cost about $2.7B.

Target Schedule

An initial demonstration should be about 1990, with a fully operational system within five years of that date.

LEO OPERATIONS BASE

Status

No significant tech ical barriers stand in the way of permanent manned occupancy of space.

Justification

Space stations have been studied since at least 1961, but have never been fully justified. There is no technical barrier to such a facility, but it must be fully justified in terms of both science and direct benefits to human needs.

Technical Plan

Objective

To define the appropriate evolution from long duration Shuttle/Spacelab missions to permanent presence of man in space.

Technical Approach

The problem is not really technical in nature, but rather economic, political and social. Studies should be initiated that provide contractors to participate fully in the growing public interest in space and the young people's dream of personal involvement. Tasks should include:

- International Involvement
- Mission Requirements
- Man's Role
- Relationship to Orbiter/Spacelab

- Evolutionary Growth
- Modular Versus Utilization of ET
- Spacelab Based Versus Original Design
- Sizing
- Timing

Resource Requirements

A 12-man space base could be placed into operation for less than $1B 1978 dollars.

Target Schedule

Any program of this magnitude takes at least five years from serious commitment to initial operating capability. This space base should be in operation either in 1986 or wait until about 1989, depending on how much on-orbit extensions of time and power we decide to add to Shuttle/Spacelab and our decisions on the overall pace of the space program.

SOLAR ELECTRIC PROPULSION

Status

Solar Electric Propulsion (SEP) systems have been studied for more than a decade. It is clear that small extensions of current technology could quickly result in a low technology SEP. However, it may be more prudent to go immediately to a higher technology level in full synergistic cooperation with overall solar power system developments including SPS.

Justification

Energy is abundant in space and is getting increasingly limited on the earth. Therefore, the use of space energy for space propulsion purposes is desirable and prudent.

Technical Plan

Objective

To accomplish inter-orbit logistics and planetary exploration with a solar powered spacecraft having low thrust, but extremely high specific impulse.

Technical Approach

The question of a two step (i.e., current solar cells, arrays, etc., and mercury engines versus SPS-type solar cells, SPS array construction and argon engines) approach versus one more advanced step is unresolved. The results of this study suggest the latter, due to the synergism between SEP, power for use in space and SPS. However, both one-step and two-step approaches have valid merits. A pre-Phase A study is suggested, concentrating on this question, but considering other tasks as follows:

- Design
- Mission Analysis
- Propellant Selection
- Solar Cell Type
- Solar Cell Array Configuration
- Trip Times
- Ion Engines
- Eclipse Effects
- Loading, Unloading, Refueling, Etc.
- Lifetime, Reliability and Maintenance
- Cost

Resource Requirements

The small study suggested would cost approximately $300K. Total program costs depend on the approach chosen and the cost sharing of technology aspects with other programs.

Target Schedule

With either approach, the SEP should be operational in the mid to later 1980's.

HIGH TECHNOLOGY CRYOGENIC OTV

Status

The technology state of OTV's reflects decisions by NASA, DoD and ESA, several years ago not to pursue the high technology upper stages, but rather postpone that work and get by with interim technology and intermediate performance.

Justification

The space transportation system (STS) is incomplete without the theme of high performance, manned reliability, and reusability being incorporated in all transportation elements. Many (even most) of the Shuttle payloads and payloads of even larger boosters in the future need to be in high energy orbits.

Technical Plan

Objective

To define a new generation LH_2, LO_2 Orbit Transfer Vehicle that meets a wide spectrum of future needs including manned missions to GSO.

Technical Approach

The basic technologies of cryogenics, hydrogen oxygen engines, composites, electronics, etc., would allow the development of an OTV that fills a wide variety of needs well into the next century. It should, therefore, be developed with key future requirements in mind, i.e., both low and high thrust modes, fully recoverable, capable of being man-rated, and Shuttle compatible. Key tasks include:

- Missions
- Sizing
- Design
- When Needed
- Reliability
- Use of RCS as Low Thrust Back-Up to the Main Engine
- Refueling
- Maintenance
- Payload Installation
- Cost

Resource Requirements

This program should follow the classic phased program development steps and be shared in cost between all users, particularly NASA, DoD and DoE It is expected to cost about $1B in 1978 dollars.

Target Schedule

The OTV should be operational in an unmanned model in 1987. The addition of a manned module payload would be subsequent to that by three to ten years, depending on mission requirements and manned versus unmanned operations in GSO.

MADE-IN-SPACE PRODUCTS

Status

The current demonstrated technology for space processing is generally not sufficient for private investors to risk large capital on a specific product.

Justification

The promise of a major industrial harvest from space has been supported by numerous studies and a few actual experiments that were conducted on spaceflights and sounding rockets. None of these appear to yet have the technical and financial basis to justify the commercial investment of large sums of money before more experiments and demonstrations are conducted.

Technical Plan

Objective

To set the stage for an avalanche of new products that are uniquely derived from utilization of the enviornment of space.

Technical Approach

Continue the on-going work in space processing with particular emphasis on developing hardware to conduct numerous experiments on early Shuttle flights. Develop a precedent understanding between government and industry that will provide government support for the early, high-risk phases, but let industry bring in investments and retain proprietary rights appropriate to traditional research and development operations in their competitive industrial environments.

Resource Requirements

Refer to MSFC long-range plans in this area.

Target Schedule

It is vital that space processing experiments be carried out on a broad basis in the early 1980's. As the results become available, significant plans for commercialization should be developed on a product-by-product basis.

LARGE SPACE STRUCTURES

Status

Studies, ground subsystems development space experiments have been carried along for most technology areas necessary for large, manned facilities in space. These were aimed toward the concept of a laboratory in space. It seems certain now that space construction is a more significant program driver than space experiments. This recent shift spotlights emphasis on the key area that was left out of the previous on-going work, that of Large Space Structures.

Justification

The main justification for large space structures comes from: (1) SPS, (2) complexity inversion, and (3) power needs for on-orbit activities. Solar Power Satellites (and to some extent Lunettas or Solettas) are the most ambitious, but also most important of the long range space utilization opportunities since they relate to the critical issue of terrestrial energy. Complexity inversion (with the goal of making ground segments of a system so small and inexpensive that millions of units will be directly interfacing with the satellite) also takes large space structures, both for antennas and power. Finally, many of the attractive made-in-space candidates would take multi-hundred kW of power in space if hundreds of tons per year were to be processed in space and utilized on earth. This requirement, plus a potential need for solar electric propulsion (SEP) makes large solar energy needed in space for in-space power. All of these require large space structure technology.

Technical Plan

Objective

To develop large space structure technology on a broad front, but emphasizing continuous space fabrication processes.

Technical Approach

The following areas of technology should be included in the large space structures approach:

- Space Fabrication
- Modeling and Scaling Laws
- Ground Test Validation Procedures
- Orbiter Assembly Operations
- Assembly and Fabrication Aids and Machinery
- Role of Man/Space Cybernetics
- Large (Flexible) Platform Attitude Control
- Long Life Films and Reflector Surfaces
- Long Life Composites
- Structuring Figure Control and RF Pattern Control

Resource Requirements

To be determined (Refer to Langley Research Center ATLAS program).

Target Schedule

Operational systems are needed as soon as practical. The recommended *Space Industrialization* plan calls for a quantim jump in the information transmission and observation areas by 1987, and multi-hundred kW power systems a year earlier. Therefore, the basic large structures technology should be early enough to support these operational systems and progress from there toward an operational SPS by the turn of the century.

SOLAR PHOTOVOLTAIC SPACE POWER SYSTEMS

Status

Solar photovoltaics have probably the most public support of all of the space and terrestrial energy options. However, this support is largely romantic rather than technical and far reaching advancements in technology are necessary to make these dreams a reality.

Justification

Abundance of power and energy has been one of the traditional hallmarks of successful industrialization on earth and the indications point to a similar requirement for *space industrialization.*

Technical Plan

Objective

To develop a set of evolutionary designs for thousands, millions, and billions of watts generated in space for in-space use — in full cooperation with corresponding studies of even larger amounts of power generated in space for terrestrial use.

Technical Approach

For both terrestrial and space power systems, the cost per watt of solar photovoltaic systems needs to be reduced by about two orders of magnitude from current prices. In addition, the space systems need to become much thinner and lighter and to maintain high efficiency over several decades of operation in the space environment. Ga Al As cells offer a reasonable possibility f achieving these goals for SPS. For terrestrial applications, silicon and other materials show some promise of meeting the cost goals set by DoE. The basic technology of solar photovoltaics, possibly in conjunction with solar heating and cooling (terrestrial), should be vigorously pursued. Tasks should include:

- Similarity to SPS Development Program
- Requirements and Timing of Requirements
- Overall Designs
- Solar Cell Materials
- Cascaded Systems
- Array Structures
- Energy Storage
- Lifetime/Degradation/Reliability
- Methods of Construction
- Cost

Resource Requirements

Refer to DoE plans for terrestrial applications and NASA SPS plans for space application.

Target Schedule

Progress is incremental and related to funding level. A technology readiness level should be achieved by 1982 that would be a significant step toward later goals and usable in the mid 1980's as operational systems.

Rockwell International
Space Division

SOLAR PHOTOVOLTAIC TECHNOLOGY

Status

Recent advances in the Ga Al As solar cell technology have shown that cells can be manufactured that have an operating efficiency of 17.5 percent at AMO and 28°c. The cells produced to date are laboratory-type cells and the largest cell fabricated is 2 x 2 cm. The cell has the potential of obtaining a 20 percent operating efficiency, but continued development work is required in order to meet this goal.

Justification

The Ga Al As solar cell appears to be superior to the Si-type cell that is presently in use. The Ga Al As cell has the potential for higher efficiency, lower weight, increased performance at elevated temperatures and more resistant to ionized radiation compared to Si cells. The use of Ga Al As cells in advanced spacecraft will result in a higher power capability with reduced degradation from thespace environment.

Technical Plan

Objective

Develop advance Ga Al As cells and demonstrate their performance and reliability for space application. Analyze the manufacturing processes and design improved technique and equipment that will result in the manufacture of high efficiency and low cost and weight cells. Test and characterize the cells to the space radiation environment.

Technical Approach

Analyze, design and fabricate prototype cells. Determine characteristics, materials, and tolerances that affect the performance of cells and upgrade to improve power output and voltage rating. Measure α and ϵ of cell, covers and cell stack. Determine effects and assess impact of reducing junction thickness on cell performance, manufacturing cost and gallium availability. Investigate and develop improved cell interconnects for large production rate. Assess optimum cell size based on cost, production array, blanket fabrication techniques and stowage and deployment constraints.

Mass production of the cells will require a review of the manufacturing concepts and selection of the concept which appears to offer a high manufacturing capability with low cost such as the metal oxide — chemical vapor deposition (CVD) process. The process variables, tolerances and the equipment size have to be defined. Establish production yields, process times, manufacturing costs and plant size which are necessary to determine production rates. Define facility requirements and cell costs. Analyze the gallium cycle for recycling, minimizing losses and reduction in gallium content for cell performance.

Conduct detailed analyses of the cell structure to determine methods and designs to increase the radiation resistance of Ga Al As cells. Perform analyses and computer modeling of the devices to determine their performance in the radiation environment. Conduct radiation tests on space-type cells and reflector specimens and correlate and compare data with math models. Develop and evaluate techniques to minimize radiation degradation such as thermal annealing of cells, increased thickness of reflector coating, development of increased radiation hardened solar cells, etc.

Resources Requirements

To be determined.

Target Schedule

To be determined.

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